THE FOOD WEB CONCEPT:
Identification Of A Learning Hierarchy And Related Misconceptions.

BETTE ANNE CRNKOVICH GRANT

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THE FOOD WEB CONCEPT: IDENTIFICATION OF A LEARNING HIERARCHY AND RELATED MISCONCEPTIONS

by

© Bette Anne Crnkovich Grant, B.Sc., B.Ed.

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ABSTRACT

The present study investigated the application of Gagné's learning hierarchy model to the learning of the concept of a food web, an important topic in biology curricula. Few validated learning hierarchies have been reported in the literature for concepts outside the realm of mathematics and the physical sciences. As a result, the application of Gagné's model in the present study provided some information regarding the applicability of the model to such a concept. In addition, the process of validating the hypothesized learning hierarchy provided a ready means by which to investigate students' misconceptions regarding skills comprising the hierarchy. Hence, a second aspect of the present study concerned the identification of common misconceptions which grade ten biology students hold regarding the food web concept. This in turn provided some information regarding the applicability of the learning hierarchy model to the study of students' misconceptions.

The sample consisted of 200 grade ten biology students from three coeducational schools in the St. John's area. A learning hierarchy was developed for the food web concept using a Gagné-type task analysis. Upon completion of regular classroom instruction on food webs, the sample was tested on the skills comprising the food web hierarchy. Following this pretest a self-instructional booklet, designed to remediate the skills of the food web hierarchy for students who had failed to learn them initially, was administered. Each subject received an individualized prescription for the remediation of skills which were

failed on the pretest. Following the remedial phase, a parallel form of the pretest was administered to the sample. These data were analyzed using two psychometric validation techniques, the ordering-theoretic and the Dayton and Macready methods. Griffiths' method was used to investigate the hierarchy in terms of its transfer validity. Data from test items which were answered incorrectly were analyzed and subjects' misconceptions were recorded.

The hypothesized food web hierarchy was found to be valid both psychometrically and in terms of transfer, although transfer of learning for connections involving lower skills of the hierarchy could not be determined because too few students failed these skills in the pretest. However, the validated hierarchy appears to offer much potential use as an instructional tool for the instruction of food webs. In addition, these findings indicate some support for the applicability of the learning hierarchy model to concepts other than those of mathematics and the physical sciences. Five common misconceptions held by grade ten biology students concerning food webs, food chains and predation were identified. In one case, a misconception was revealed for a large part of the sample in items testing subordinate skills, but did not occur in the case of the terminal skill. This suggests that the learning hierarchy model may be useful in the study of misconceptions, in that it has the ability to reveal underlying misconceptions which would not be apparent from students' responses to the terminal skill alone.

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THE PROBLEM

Introduction to the Problem

It is the task of the curriculum developer to set the sequence of instruction, to determine 'what must come before what' (Schwab, 1964b, p. 11). Taba (1962, p. 290) expressed the significance of this task to learning:

> Often the curriculum is ineffective not because its content is inadequate, but because it is put together in a way that makes learning difficult. . . .

At the instructional level, it follows that difficulties which students encounter with important concepts in science and other areas of study might be alleviated by improved sequencing of instruction. This is of particular significance when the learning of one element of instruction may facilitate the learning of another. In such a case, Briggs (1967, p. 4) suggests that careful sequencing of elements in terms of the direction of such transfer should be more effective than random sequencing. Thus, knowledge of the sequence in which elements of knowledge should be learned could provide a valuable tool for shaping effective instruction (White, 1973).

Despite several decades of research effort which has addressed the problem of how to identify optimal sequences of instruction (Dewey, 1916; Bruner, 1960; Piaget, 1964; Schwab, 1966; Gagné, 1977), what has emerged is not a solution, but the realization that more research is needed before valid recommendations for practice can be made (Posner & Strike, 1976, p. 665). While no general recommendations have been made, there does appear to be substantial interest in the study of instructional sequencing.

From the literature it is apparent that the sequencing problem may be studied at various levels, depending upon the size of the instructional unit to be sequenced. On a "macro" level, sequencing efforts focus on very large blocks of curriculum. An example of this level of sequencing is Comte's positive hierarchy of the sciences in which several entire disciplines are organized into a suggested sequence of study (cited in Schwab, 1964b, p. 18). Schwab (1964a, p. 11), however, notes the fallacy in attempting to delineate a preferred sequence of instruction at this level:

> . . . the problem of the organization of the disciplines is a problem of classification primarily. The diversity and variety of available modes of classification is great. Consequently, nothing could be more foolish than to suppose that the problem posed to us by this variety of doctrines is the problem of determining which one is "right". With very few exceptions, each of them is, in its own way, "right".

In this respect, sequencing on a macro level seems to involve a curricular decision more so than an instructional one. Consequently, the problem of the identification of sequences which may improve learning appears to be more likely for smaller units of instruction. In his review of the literature relating to sequencing of instruction, Briggs (1967, p. 12) suggests it would be most expedient to focus on brief units of instruction. On such a "micro" level, sequencing efforts would be directed towards elements of a single lesson. Gagné (1973) takes a similar view, suggesting that learning hierarchies, which represent one approach to sequencing, are most clearly applicable to units consisting of single lessons.

There is some support for directing sequencing efforts toward units of instruction intermediate to those of the macro and micro levels described above. Despite acknowledging the merits of focusing research efforts on single units of instruction, Griffiths (1979, p. 17) suggests that sequencing efforts representing such small units of instruction are unlikely to be considered of significant value to educators. He proposes that sequencing efforts involving several lessons may allow sufficient experimental control, and still be useful to teachers. This is the position taken in the present study.

In addition to differences concerning the size of the instructional unit to be sequenced, the sequencing problem may be considered with respect to another variable, namely the rationale used to order an instructional unit in a particular way. While almost all theoretical positions acknowledge the importance of effective sequencing, alternative ways of conceptualizing the sequencing problem exist (Briggs, 1967, p. 15). Posner and Strike (1976) have proposed a conceptual framework for studying these alternative perspectives of instructional sequencing, as well as their implications for sequencing research. Their framework outlines five distinct categories of sequencing principle: world-related, concept-related, learning-related, inquiry-related and utilization-related, each with a number of subcategories. Most investigators appear to focus their research within a given category or subcategory.

The present study grew in an attempt to alleviate difficulties students may encounter in understanding an important concept in high school biology, namely, food webs. For several reasons, Gagné's learning hierarchy theory was considered a promising model from which to approach the problem.

First, such learning is representative of the domain of intellectual skills, as defined by Gagné (1972). According to Gagné, intellectual skills are particularly amenable to the application of the learning hierarchy model. The rule-like nature of the relationships in food webs suggested that a potentially profitable approach through which to promote more effective learning would be the learning hierarchy model. Second, the task analysis and subsequent data collection phases in the development and validation of the learning hierarchy would provide an opportunity to reveal common misconceptions which students may harbour regarding the food web concept. Current science education research reflects growing support for the need to identify misconceptions held by students with respect to particular science concepts. For example, Finley and Stewart (1982) suggest that research to identify knowledge of commonly taught content domains which students have prior to instruction would be valuable to teachers and curriculum developers. They suggest that this information could be used in planning instruction to include missing knowledge and to correct common misconceptions. A learning hierarchy has several built-in diagnostic features which are useful in pinpointing areas of difficulty experienced by individual students (Okey & Gagné, 1970; Reid, 1981). Presumably, a food web hierarchy could provide a powerful tool for diagnostic testing and remedial teaching in this area.

A third reason for considering the use of Gagné's model in the present study became apparent from a review of the literature. Here it was observed that studies incorporating Gagné's learning hierarchy model rarely focus on concepts central to the biological sciences. White and Gagné (1974) underscore the need to determine whether valid hierarchies exist in subject areas other than mathematics and the physical sciences. The present study may contribute to this.

Prior to discussing Gagné's hierarchical model of learning in greater detail, it is important to acknowledge an alternate learning theory which has been more widely applied to biology education than has the Gagnéan model, namely, Ausubel's reception learning paradigm (Ausubel, 1963; Ausubel, Novak & Hanesian, 1978). Ausubel's work is concerned largely with the learning of verbal knowledge. Gagné (1977) appears to agree with Ausubel's views for this type of learning. Perhaps because a large part of biology education involves the learning of verbal knowledge, Ausubel's theory has gained wide popularity among biology educators. Yet biology, like other disciplines, involves other domains in addition to verbal knowledge--including that of intellectual skills. Accordingly, Gagné's theory is also relevant to biology education, and for the content under consideration in the present study, appears to be the most promising model.

Gagné's Hierarchical Model of Learning

As a learning theorist, Robert Gagné has made many contributions to current views of learning. His hierarchical model of learning (Gagné & Paradise, 1961; Gagné, 1962) has received much attention in the 20 years since its inception. The development of the model as well as changes and refinements that have helped to clarify its basic premises will now be considered.

Despite origins in the behaviourist tradition, Gagné clearly dismisses the notion that any one prototype of learning can be applicable to the domain of learning as a whole. This belief in different types of learning led Gagné (1965) to propose that there may be as many different types as there are different conditions under which learning takes place. The importance of this idea to Gagné's work is reflected in the title of his major text, "Conditions of Learning" (1965, 1970, 1977).

Gagné (1965) proposed that there were eight types of learning, and further, that these types form a hierarchical arrangement in which types representing simpler, more specific capabilities are prerequisite to the learning of the next, more complex, capabilities. A slightly modified version of this model is illustrated in Figure 1. As most children of school age will have already developed a foundation in the learning types comprising the lower half of this model, it is suggested that the upper four types are most significant to those concerned with the instruction of these students. Only the upper types are represented in the model shown in Figure 1.

The basic premise underlying learning hierarchies is that failure to learn a particular skill is principally due to a lack of essential subordinate skills, and correspondingly, that learning should be easy to induce if all relevant subordinate skills are possessed by the learner (White & Gagné, 1974). Gagné (1968) urges that a learning hierarchy does not represent a unique or most efficient route to the learning of a given final task for all learners. He suggests that a given individual may be able to miss one or more of the subordinate tasks, while another may be able to apply some capability which comes from quite a different domain of knowledge not represented in the

HIGHER-ORDER RULES

require as prerequisites

RULES

which require as prerequisites

CONCEPTS

which require as prerequisites

DISCRIMINATIONS

which require as prerequisites

Basic Forms of Learning: Associations and Chains

Figure 1. Gagné's (1977, p. 34) representation of types of intellectual skills.

hierarchy. Generally, however, for a validated hierarchy it is anticipated that most learners will benefit from following the sequence (Gagné, 1968).

In response to the question of how a learning hierarchy is generated, Gagné (1968, p. 3) suggests that for each task encountered one should ask, "What would the individual already have to know how to do in order to learn this new capability simply by being given verbal instructions?" The same question is asked successively for each new capability produced. The resulting structure may be linear, or where two or more subordinate skills are prerequisite to a higher skill, branched. Gagné (1968) suggests that the question by means of which the analysis is begun implies that one is searching for subordinate tasks that will transfer positively to the learning of the superordinate task in question. In this way, when a subordinate skill is mastered, it is suggested that the learning of the related superordinate skill will be facilitated; and conversely, if the subordinate skill has not been mastered, that there will be no facilitation of the superordinate skill. The crucial test of the validity of a hierarchy throughout Gagné's writings has been the extent to which learning of a subordinate skill effects positive transfer to the learning of superordinate capabilities. Those who fail to exhibit prerequisite capabilities are predicted to fail to exhibit related superordinate capabilities, while those who exhibit prerequisite capabilities are expected to be more likely to exhibit superordinate capabilities. The corollary, that increasing the proportion of learners who can exhibit the prerequisite skills will result in a significant increase in the proportion who can exhibit the superordinate skills, represents the essential test of the existence of a hierarchy (Gagné, 1968).

Although reviews of studies incorporating the learning hierarchy model had generally encouraged further application of the model (Briggs, 1967; Resnick & Wang, 1969; Walbesser & Eisenberg, 1972; White, 1973), they also revealed certain anomalies. This led to a reconsideration of the model on the part of Gagné, which ultimately resulted in a reclassification of the nature, characteristics and uses of learning hierarchies (Gagné, 1972). In addition, the development of more rigorous validation procedures has led to further clarification of the learning hierarchy concept, and of the component elements of hierarchies. These will now be discussed.

An important characteristic of hierarchies involves the capabilities which comprise the hierarchy. Originally, Gagné suggested that his hierarchical model applied to all types of learning (Gagné, 1965). However, anomalies in research findings eventually led Gagné (1972) to propose a restriction of the use of his hierarchical model to certain kinds of learning. Where he originally outlined eight types of learning (Gagné, 1965), Gagné now postulates five domains of learning: learning of intellectual skills, cognitive strategies, motor skills, verbal information and attitudes (Gagné, 1972). The eight types of learning which were originally distinguished are now considered to represent components of one domain of learning, intellectual skills. Although his classification of learning types has changed somewhat, Gagné's basic belief in the existence of different types of learning, each requiring different conditions for learning, remains intact.

This reclassification of learning types was accompanied by a clarification of the role of learning hierarchies. Gagné (1968) proposes that the hierarchical model represents the most essential component of the conditions proposed for the learning of only one domain, intellectual skills. Although empirical evidence may support the need to identify prerequisite behaviours in any domain, it does not support the suggestion that these prerequisites form a learning hierarchy in any domain other than that of intellectual skills (Gagné, 1968). With this view, Gagné (1968, p. 5) has redefined a learning hierarchy to be

> . . . an ordered set of <u>intellectual skills</u> such that each entity generates a substantial amount of positive transfer to the learning of a not-previously-acquired higher-order capability. (emphasis mine)

Although each domain of learning has an important role in education, Gagné (1974) advises that the identification of hierarchies of intellectual skills cannot be overemphasized. Not only does the domain of intellectual skills represent a substantial part of school learning, but development in the domains of cognitive strategies, verbal information, motor skills and attitudes appears to require the prior learning of relevant intellectual skills (Gagné, 1977).

In proposing that hierarchies contain only intellectual skills, and not elements from other domains, Gagné (1970) does not intend to suggest that the capabilities comprising each of the other domains are irrelevant to the learning of intellectual skills, rather, because they do not exhibit a consistent relationship to intellectual skills in the hierarchy, he suggests they cannot be considered a part of the hierarchy.

Gagné's views have also changed somewhat with regard to the preferred amount of instruction to be included in a learning hierarchy. Originally, he proposed there was no limit to the amount of content to be included (Gagné, 1963). More recently, Gagné (1973) suggests that learning hierarchies are most applicable to the content of a single lesson, although arguments have been proposed for the inclusion of more than this (Griffiths, 1979, p. 17). As such, the question of how much content should be included in a learning hierarchy has not been defined absolutely.

Although it was not intended that this section represent a comprehensive treatment of Gagné's work, the basic principles and applicability of the learning hierarchy model have been described. Following a definition of terminology used in the present study, the application of this model will be discussed.

Definition of Terms

Capability: The ability to perform a specific function under specified conditions; e.g., the ability to determine how a sudden increase in a given population in a food web would affect another, non-adjacent, population located lower on the same chain within the web.

Community: A group of interacting populations existing together in a particular habitat.

Food Chain: A simplified model to describe feeding relationships between populations in a community, in which nutrients are shown to pass through a series of populations arranged in sequence.

Food Web: A relatively complex model to describe feeding relationships between populations in a community, in which nutrients are shown to pass through a network of interconnecting food chains.

Hierarchical Connection: A relationship between two skills such that the learning of the lower skill is necessary for and/or enhances the learning of the upper skill.

Intellectual Skill: Knowing "how" as contrasted with knowing "that" of information (Gagné, 1968, p. 4); e.g., knowing how to determine the effect of a change in one population on another population in a food web, as opposed to knowing that populations in a food web interact.

Learning Hierarchy: An arrangement of intellectual skills in which skills are related to other skills through subordinate-superordinate relationships, such that the subordinate skill in each pair is necessary for the learning of the superordinate skill and/or exhibits transfer of learning to the superordinate skill.

Population: A collection of individuals of the same species co-occurring in time and space, among whom there is no barrier to breeding; as in the ecological definition of this term.

Subordinate Skill: The lower skill in a hierarchical connection between two skills, which is necessary for and/or enhances the learning of the upper skill.

Superordinate Skill: The upper skill in a hierarchical connection between two skills.

Need for the Study

The need for the present study may be assessed from three vantage points. The first addresses the educational needs of the learner; that is, the importance of the food web concept to a student's education and the ensuing need to investigate a potentially useful method by which to teach this concept. Understanding the concept of a food web forms an important part of most high school biology curricula. In a study in which 100 biology teachers were asked to rate 55 major biology topics according to their importance, "food webs" was rated as one of the 15 most important topics (Finley, Stewart & Yarroch, 1982; Stewart, 1982). One reason for the importance teachers place upon an understanding of the food web concept is its role as a basic ecological principle. Before students can understand complex ecological concepts, they must have a firm grasp of the basic tenets. Alexander (1982) suggests that the ability to understand and analyze a food web appears to be central to an understanding of more complex ecological principles. In light of a leading professional ecologist's view that "We are abysmally ignorant of the ecosystems of which we are dependent parts" (Odum, 1977, p. 1289), the importance of the food web concept becomes apparent.

Alexander (1982, p. 189) proposes that perhaps at issue is not the "need", but rather the "how" to teach principles of ecosystems; and that one of the most effective means is through the study of a food web. The food web model represents feeding relationships among various populations living in a given community. The concept behind this model implies that individual populations in a given community do not live in isolation from each other; they depend upon each other for food. If the size of one population undergoes an extreme change, thereby affecting its feeding potential, other populations in the food web will be directly or indirectly affected. By understanding the concept of a food web, students will be better able to understand how a phenomenon which drastically alters one member population of a food web will ultimately affect other populations in the community comprising that web. This is an important ecological principle which is critical to an understanding of environmental issues including pollution, conservation and population management; issues about which students may be called upon to make decisions as conscientious members of society. In addition, Coletta and Bradley (1981) advise that the food web concept, with its many interacting branches, can offer a realistic understanding of natural environments. Such an understanding is essential if society is to successfully balance use with conservation.

Although teachers rate the food web concept as an important part of biology curricula, Finley, Stewart and Yarroch (1982) suggest that they do not perceive food webs and related concepts to be particularly difficult. Yet Johnstone and Mahmoud (1980a) note that examiners' reports on school-leaving examinations in Scotland over an eight-year period indicated that students experienced substantial difficulty. It appears, therefore, that there is a need to identify particular difficulties and misconceptions which students encounter in learning the food web concept, so that teachers may work to prevent or alleviate them. This leads to the consideration of a second need to which this study may respond, and an emerging area of substantial interest in science education research: the identification of students' misconceptions and alternative conceptions (Driver &

Easley, 1978) of scientific phenomena. Stewart and Atkin (1982) note that a great deal of empirical research is needed to assess the knowledge and procedures utilized by students in solving problems in particular content domains, and that research of this type has direct implications for science teachers. Upon addressing the question of what represents relevant research in biology education, Stewart (1980) cites the need for research dealing with misconceptions which students develop as a result of instruction, as well as the identification of preconceptions which they bring to the classroom. Very few studies of misconceptions have related to biological concepts, although Brumby (1982) reports data relating to students' misconceptions of "life" and Deadman and Kelly (1978) report on misconceptions concerning "evolution." It is particularly timely, therefore, to add to the literature on students' misconceptions about biological phenomena.

Finally, few validated learning hierarchies have been reported in the literature for concepts outside the realm of mathematics and the physical sciences. The present study may provide information regarding the applicability of this model to such a concept. Beeson (1977) addresses the need to test the concept of learning hierarchies in a variety of curriculum areas. He claims it is necessary that the nature and limits of the application of learning hierarchies in various curriculum areas must be investigated if they are to have practical application in the development of instructional sequences. This study attempts to investigate the application of Gagné's learning hierarchy model to a biological concept.

Purpose of the Study

The primary purpose of this study is to identify a learning hierarchy leading to the learning of the concept of a food web. The hierarchy will be considered with respect to both its psychometric and transfer characteristics.

A secondary purpose is to determine particular misconceptions held by grade ten biology students with respect to intellectual skills which lead to the learning of the food web concept.

Research Questions

Question 1: Does the arrangement of intellectual skills represented in the hypothesized hierarchy represent a learning hierarchy which is valid psychometrically?

Question 2: Do any connections between pairs of intellectual skills comprising the hypothesized hierarchy represent connections which are valid in terms of transfer of learning?

Question 3: What misconceptions do grade ten biology students hold with respect to the intellectual skills comprising the hypothesized hierarchy?

Delimitations of the Study

Restriction of the sample to one grade level (grade ten) within the St. John's area of Newfoundland represents an important delimitation of the study. Evidence gathered from one grade level may not be generalizable to higher or lower grades. Also, it is possible that students from schools other than the three sample schools may respond differently, although there is no particular reason to believe this. It is also possible that students from geographical areas external to Newfoundland may not respond in the same way as the sample, although again there is no particular reason to suspect this.

The study is further restricted to one particular topic in biology. Identification of a valid hierarchy for this topic, or failure to do so, does not imply anything about the hierarchical nature of biology in general or any other science.

Finally, any hierarchy which is developed may not represent the only valid hierarchy for the concept under study; nor is it possible to deny that some hierarchy may exist even if one is not found.

Limitations of the Study

A limitation of the study exists in that the investigator had little control over sample selection. It was necessary that the study coincide with the teaching of the concept of a food web in the classroom. Therefore selection of schools was limited to those studying food webs in sufficient detail and at the particular time.

A second limitation involves the remediation of skills. Although each student received a booklet indicating which skills were to be studied, there was no control over whether the students did, in fact, use the booklet. This may have reduced any observed transfer effect. In an attempt to minimize this limitation, an effort was made to design a booklet which was appealing to students. It is also possible that despite utilizing the booklet as directed, some students may not have successfully remediated missing skills. This could be due to difficulties in learning from a self-instructional format or from inherent weaknesses in the booklet as an instructional tool; however, great care and effort were taken to produce an effective learning package.

As no measuring instrument is free of error, the instruments used in the present study represent a further limitation. Ideally, students should respond to items testing the same skill consistently. If items representing a given skill differed with respect to format or presentation, measurement errors could result. Because of the nature of the skills being tested in the present study, this limitation is less serious. The items comprising the test instrument test skills involving food web diagrams, and two items testing a given skill differ only by slight modifications in the structure and lettering of their respective diagrams.

Overview

From the time of the earliest studies involving Gagné's learning hierarchy model, investigators have wrestled with various methods by which to validate proposed learning hierarchies. The next chapter involves a description and discussion of techniques which have been used to identify learning hierarchies. Several recent methods which were applied in the present study are discussed in detail. The chapter concludes with a description of empirical studies relating to the development and application of hierarchies in science. The design of the study and a description of the test instruments and procedures used are presented in Chapter 3. Chapter 4 describes the analysis of data and the results obtained from the study. The report concludes with Chapter 5 which includes a summary of the study and the major conclusions and recommendations for further research.

Chapter 2

A REVIEW OF RELATED RESEARCH

Introduction

Learning hierarchy research has developed in the two decades since Gagné first proposed his model (Gagné & Paradise, 1961; Gagné, 1962). With increased interest in Gagné's theory came improvements in methods of statistical analysis and experimental design of hierarchy studies. A review of learning hierarchy research traces these developments.

This chapter begins by considering the development of a model for the design of learning hierarchy studies, followed by a presentation of methods of hierarchy validation. The second half of the chapter considers studies investigating learning hierarchies in science and the application of learning hierarchies to the study of students' misconceptions.

The Design of Learning Hierarchy Studies

Much of the research reported in the literature since Gagné's (1962) preliminary study has been concerned with proving or disproving the existence of learning hierarchies. In a major review of hierarchy research, White (1973) found positive but inconclusive support for the existence of learning hierarchies. Problems in validation methodology, for the most part, were cited as the reason.

Early hierarchy studies (Gagné & Paradise, 1961; Gagné, Mayor, Garstens & Paradise, 1962) employed a method of teaching naïve students the skills comprising a hierarchy, followed by the administration of a posttest of all skills, arranged in random order. White (1974b, p. 1) criticized these and other studies conducted in the following decade, citing several shortcomings:

1. Hierarchies were not always checked to ensure a "common-sense validity" before collecting empirical data.

2. Many studies used too few students.

3. Hierarchy elements were indiscreetly or loosely defined, which led to uncertainty in determining the possession of the element.

4. Tests sometimes included only one item per hierarchy element, preventing any estimate of chance errors or successes.

5. There was too much delay between instruction and testing.

6. Investigators did not look for additional hierarchical connections; only those postulated were tested.

7. No objective method was used consistently to determine the validity of proposed hierarchical connections.

8. Verbal information or rote knowledge was often included in the hierarchies to be investigated.

In order to improve the quality of research investigating Gagné's learning hierarchy model and thereby give greater credence to supportive findings, White (1974b, 1974c) proposed a new model for the identification and validation of hierarchies. He outlined nine stages which investigators should follow to overcome weaknesses which were prevalent in studies up to that time. White's (1974b, p. 2) recommendations are:

Stage 1: Define, in behavioral terms, the element which is to be the pinnacle of the hierarchy.

Stage 2: Derive the hierarchy by asking Gagné's question ("What must the learner be able to do in order to learn this new element, given only instructions?) of each element in turn, from the pinnacle element downward. Include all connections that seem reasonably possible, since the validation process can only destroy postulated connections, not create them. Avoid verbalized elements, they can be included in the instructions.

Stage 3: Check the reasonableness of the postulated hierarchy with experienced teachers and subject-matter experts.

Stage 4: Invent possible divisions of the elements of the hierarchy, so that very precise definitions are obtained.

Stage 5: Carry out an investigation of whether the invented divisions do in fact represent different skills.

Stage 6: Write a learning program for the elements, embedding in it test questions for the elements. The questions for an element should follow immediately after the frames that teach the element. There must be two or more questions for each element to allow for an estimate of their reliability.

Stage 7: Have at least 150 students, suitably chosen, work through the program, answering the questions as they come to them.

Stage 8: Analyze the results to see whether any of the postulated connections between elements should be rejected.

Stage 9: Remove from the hierarchy all connections for which the probability under H_o is small, say 0.05 or less.

Since the publication of White's model, several modifications have been suggested. White and Gagné (1978) eliminated stages 6 and 7 by testing subjects on all skills of a hypothesized hierarchy after they had received regular classroom instruction. The results of this study were consistent with White's (1974b) findings which tested the same hierarchy but included stages 6 and 7 in the experimental design. As a result, it was suggested that programmed instruction and the process of testing during instruction may not be essential stages in the investigation of learning hierarchies. In a later study, Griffiths (1979, p. 121) also supports the elimination of these stages, for two reasons. If the structure of any particular learning hierarchy is independent of instruction, as Gagné (1973, p. 21) suggests, it should not be necessary to restrict instruction to a programmed format, as White (1974b) recommends. Secondly, Griffiths (1979, p. 123) advises that testing after instruction is more appropriate than testing during instruction. White (1974b) suggests that testing after the instructional process is complete is likely to be misleading if subordinate skills are forgotten by the time of the final test. However, Griffiths (1979, p. 123) points out that White's method of testing during instruction may produce anomalies if the learning of missed skills takes place as a result of the initial testing process. He also suggests that immediate testing may produce anomalies as a result of short-term memory effects. Griffiths (1979, p. 122) proposes a further alteration of White's (1974b, 1974c) model in recommending the inclusion of a method to provide evidence of positive transfer between skills. These modifications were adopted in the present study.

White's (1974b, 1974c) model addressed the need for the improvement of the experimental design of learning hierarchy studies. The following sections focus upon the development of improved statistical methods for the validation of learning hierarchies. Following a presentation of early methods of hierarchy validation, more recent methods, including those used in the present study, are discussed.

The Validation of Learning Hierarchies

From the time of Gagné's pioneering studies (Gagné & Paradise, 1961; Gagné, 1962; Gagné et al., 1962), researchers have wrestled with the problem of determining the validity of proposed hierarchical connections. Hierarchy validation techniques have since become the focus of much research.

Two major hypotheses are associated with Gagné's learning hierarchy model. The prerequisite skills hypothesis assumes that each subordinate skill in a hierarchy is necessary for the mastery of its related superordinate skill(s). This is not to say that possession of a subordinate skill will guarantee that related superordinate skills are mastered; however, it is assumed that a superordinate skill cannot be mastered unless related subordinate skills have been mastered. The positive transfer hypothesis assumes that if one skill is subordinate to another, mastery of the subordinate skill will facilitate the learning of the other skill. Hierarchy validation methods reflect these hypotheses, falling into two general categories: those reflecting the transfer properties of hierarchies, and psychometric techniques which reflect the notion of a relatively inviolate sequence. The latter are further classified into those involving scaling, and those based upon the use of contingency tables, or matrices.

Some researchers have tended to utilize a psychometric definition of hierarchical dependence, while others have focused upon the extent of transfer of learning between hierarchically-related skills. Resnick (1973) observes that learning psychologists and instructional designers tend to define hierarchies in terms of asymmetrical transfer relationships between skills. Two tasks are then considered to be hierarchically related if learning the subordinate task produces positive transfer in learning the superordinate task. Testing and evaluation specialists seeking to develop efficient diagnostic and placement tests for individualized educational programs have approached validation differently: two tasks are considered to be hierarchically related when anyone who can perform the superordinate task can reliably be expected to perform the subordinate task (Resnick, 1973). Psychometric validation procedures appear to be most directly suited to this rationale. White (1973) and White and Gagné (1974) suggest that experimental validation of the transfer hypothesis of a hierarchy is more definitive than psychometric validation, however they point out the application of transfer validation procedures to a complex hierarchy may be quite laborious. Carroll (1973) tends to support this view, noting that validation experiments involving transfer can be difficult and time-consuming. It is therefore not surprising that most attempts to validate hierarchies have tended to employ psychometric techniques (Cotton, Gallagher & Marshall, 1977). Despite this observation, several investigators (Carroll, 1973; White & Gagné, 1974; Griffiths, 1979; Bergan, 1980) have stressed the importance of transfer. Carroll (1973) claims that the concept of transfer incorporates a way of testing whether the ability to demonstrate a particular task is really prerequisite to performance in another task; and that psychometric validation is only useful in searching for pairs of tasks which might be tested for hierarchical relations by the transfer criterion.

Griffiths (1979, 1982) is critical of studies in which either the psychometric or the transfer definition of hierarchical dependence has been applied exclusively. He maintains that both types of validation methodology are of sufficient importance that ". . . an hierarchy validated by either but not both approaches should be regarded as incompletely validated" (Griffiths, 1979, p. 66). This claim is supported by the argument that although it can be shown empirically that a given skill is not learned without prior learning of a second skill, this does not necessarily mean that learning the second skill helps a group of learners to learn the other skill. Conversely, a significant positive correlation between the learning of the two skills does not mean that the learner must master the second skill first (Griffiths, 1979, p. 66). In a similar vein, Resnick (1973) suggests that dependency relationships between two tasks which have been psychometrically validated show only that under existing cultural or educational conditions one task is normally learned before the other, and that such a relationship does not indicate transfer from one skill to another. Thus, when there is support for a hierarchical relationship between two skills in terms of both transfer and observed sequence of learning, a more legitimate claim for the existence of hierarchical relationship might be made (Griffiths, 1979, p. 66). Other investigators appear to support this rationale and have reported both psychometric and transfer characteristics of hierarchies (Wiegand, 1973; Bergan & Jeska, 1980). Both types of validation procedure are applied in the present study.

Despite the development of numerous validation procedures, a problem remains in specifying precisely what constitutes a valid hierarchy. As a result, investigations of learning hierarchies have often suffered from the lack of a useful, objective way of deciding whether each connection is valid or not (White, 1974a). A learning hierarchy consists of a network of connections between pairs of intellectual skills. Ideally, if a psychometric test of validity is applied, there should be no exception to the superordinate-subordinate relationship hypothesized for each connection in the hierarchy. Similarly, if the test which is applied is of the transfer type, all individuals who learn subordinate skills in the hierarchy should learn the respective superordinate skills. Griffiths (1979, p. 43) has identified two problems which complicate these ideal situations, however. In the first case, he notes that in an experimental situation it is not unreasonable to modify the ideal relationships described above to allow some exceptions. This implies that the validity of a hierarchy will be assessed in terms of substantial, rather than perfect hierarchical dependence. Complications arise as individual investigators vary with respect to their perception of what constitutes "substantial" dependence. A second complication arises because, except in the previously described ideal situations, a hierarchy which has been declared valid either according to a psychometric test or a transfer test will not necessarily be valid according to the other. Moreover, Griffiths (1979, p. 44) notes that the application of different transfer tests or different psychometric tests may also lead to different decisions regarding the validity of the hierarchy, although such problems are not always severe in practice. For example, Griffiths (Griffiths & Cornish, 1978; Griffiths, 1979) found ~~similar~~ results when three different tests were applied to the same data.

Reviews by Briggs (1967), Resnick and Wang (1969), Walbesser and Eisenberg (1972), White (1973), Cotton et al. (1977), Jones and Russell (1979) and Bergan (1980) attest to the breadth of research which has been generated by the learning hierarchy model. Although each reviewer has been supportive of the basic model, most have outlined limitations in the statistical methods used in the validation of learning hierarchies. Some early statistical methods which have been used in hierarchy validation are considered briefly in the next section. A presentation of more recent methods, including those used in the present study, follows in later sections.

Early Hierarchy Validation Techniques

Learning hierarchy research began with a series of studies conducted by Gagné and his colleagues which investigated the learning of mathematics skills (Gagné & Paradise, 1961; Gagné, 1962; Gagné et al., 1962). In each case it was discovered that the skills formed a sequence in which, generally, subjects did not learn a later skill in the sequence unless they had previously learned all of the earlier skills. Any exceptions to the proposed hierarchical connections were considered to be the result of errors of measurement. From these studies Gagné derived the concept of positive transfer, in which he proposed that the learning of earlier skills enhanced the learning of later skills. In order to provide a summary measure of the validity of each hierarchical connection, Gagné developed a descriptive index called the "index of proportion positive transfer." Unfortunately, several significant limitations of this index have since become apparent. White (1974b) demonstrated that the index may merely reflect a positive correlation between skills; a necessary criterion, but one which is insufficient in terms of hierarchical relationship. In addition, he indicates that the index takes no account of errors of measurement and lacks a sampling distribution. In an effort to overcome some of the weaknesses of the index of proportion positive transfer, Eisenberg and Walbesser (1971) proposed a series of indices of positive transfer; however these were also found to have several flaws (Capie & Jones, 1971; White, 1974a; Griffiths, 1979, p. 47).

Resnick and Wang (1969) attempted to use Guttman's coefficient of reproducibility (Guttman, 1944) as a measure of the validity of hierarchies. It differs from the indices previously discussed, as it is a single figure which applies to the whole hierarchy, not to individual connections within it. As a result, one incorrect connection could lead to the rejection of the whole hierarchy. White (1974a) notes that it is difficult to interpret this coefficient when a hierarchy is complex and branching, and like the other indices, this measure takes no account of errors of measurement and has no sampling distribution.

Capie and Jones (1971) proposed the use of the phi coefficient in the validation of a learning hierarchy, however their criteria appear to be necessary, but not sufficient, conditions for a valid hierarchy. White (1974a) warns that use of these criteria alone can lead to a hierarchy which contains superfluous skills and superfluous connections between skills.

Each of the methods of hierarchy validation which has been outlined in this section has been considered unsatisfactory for one or more reasons (White, 1974; Cotton et al., 1977; Griffiths, 1979; Bergan, 1980). White and Clark (1973) proposed a hierarchy validation method which avoids the above problems and provides a probabilistic estimation of the validity of hypothesized connections between pairs of skills.

The method has been applied by White (1973), Linke (1975), Beeson (1977) and others. However, Owston (1979) has shown it to be faulty in terms of the assumptions underlying its parameter estimates in some circumstances.

The two psychometric validation techniques used in the present study are described in the following sections.

The Ordering-Theoretic Method

In the ordering-theoretic method (Bart & Krus, 1973; Airasian & Bart, 1975), the validity of a hierarchy is determined by considering the relationships between pairs of skills. Although an arbitrary test of the validity of each hierarchical connection is used, the ordering-theoretic method is very simple to apply and has been shown to yield results not significantly different to those obtained from the application of the White and Clark test (Griffiths, 1979). In the present study the ordering-theoretic method is used to provide an initial analysis of the data, after which hierarchical connections are tested further by application of the Dayton and Macready (1976a) method.

In the ordering-theoretic method, decisions regarding the validity of hypothesized hierarchical relationships are made on the basis of scores represented in matrices for pairs of skills. Such a matrix is presented in Figure 2, where the letters A, B, C and D refer to the frequency of subjects exhibiting each of the pass-fail relationships described below:

A = the number of subjects who pass both the upper skill and the lower skill.

B = the number of subjects who fail the upper skill and pass the lower skill.

		UPPER SKILL SCORE	
		Fail (0)	Pass (2)
LOWER SKILL SCORE	Fail (0)	C	D
	Pass (2)	B	A

Figure 2. An ordering-theoretic skills matrix.
Note: A, B, C and D represent cell frequencies.

C = the number of subjects who fail both the upper skill and the lower skill.

D = the number of subjects who pass the upper skill and fail the lower skill.

The frequency of each cell of the matrix is determined from empirical data.

The ordering-theoretic method focuses upon the percentage of subjects whose responses are disconfirmatory to the existence of a hierarchical connection between two skills, those passing the upper skill and failing the lower skill. Ideally, if the hypothesized lower skill is prerequisite to the hypothesized upper skill, the frequency of cell D, the critical cell, should be zero. However, in order to allow for errors of measurement, Airasian and Bart (1975) suggest setting an arbitrary, prespecified tolerance level for cell D. Typically, 1%, 2% or 5% exceptions have been allowed. Hence, in a study of 100 subjects, a tolerance level of 5% would allow a maximum of five subjects to fall in the critical cell without rejection of the hypothesized hierarchical connection.

The application of the ordering-theoretic method requires prior correct classification of subjects as masters or nonmasters of each skill in the hierarchy. If each skill is tested by two items, a score of "2" would represent possession of the skill, and a score of "0" would represent nonpossession. Because subjects with an intermediate score of "1" could not be clearly classified as possessing or lacking a given skill, in the present study these cases were labelled "missing data" and omitted from the analysis. This practice was adopted in an attempt to increase the certainty of classification of mastery status and thereby increase confidence in the validity of any hierarchy which may emerge.

As might be expected, one of the major limitations of the ordering-theoretic method is the arbitrary nature of the tolerance level set for the critical cell. The choice of an appropriate tolerance level appears to be left to the discretion of the investigator. As a result, it is possible that different investigators using the same data could arrive at different conclusions regarding the validity of a given hierarchy.

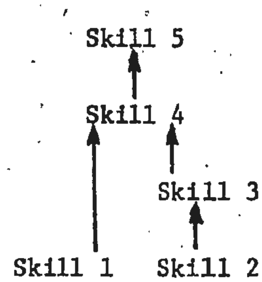
Wood (1975) defined a significance test for the ordering-theoretic method which was based upon the total number of hierarchical relationships between all task pairs that exist for a set of tasks. Basically his test determines the chance probability of obtaining an observed number of hierarchical relationships. However, Cotton et al. (1977) point out that the Wood procedure is biased against confirmation of simple hypotheses with small numbers of hypothesized hierarchical relationships.

Unlike the ordering-theoretic and White and Clark methods, the Dayton and Macready model is capable of considering the hierarchy as a whole, at least for small hierarchies. This model is described in the next section.

The Dayton and Macready Model

The basis of the Dayton and Macready (1976a) model may be traced to Guttman scaling (Guttman, 1944). The ideal form of a Guttman scale, applied to a linear learning hierarchy, occurs when responses of a number of individuals to several test items form a sequence such that all individuals who make a correct response to any particular item also make correct responses to all earlier items. To maintain some standard for acceptance or rejection of a scale, while still allowing for some reasonable level of error, Guttman (1944) derived an "index of reproducibility." An arbitrary reproducibility value of at least 0.90 was declared necessary for the hypothesized scale to be considered valid. Proctor (1970) made a significant advance by replacing Guttman's index with a probabilistic estimate. Although Proctor's model has not been applied directly to the validation of learning hierarchies, it forms the basis of Dayton and Macready's (1976a) attempt to extend scaling to hierarchies of any configuration. Dayton and Macready's model also made use of Proctor's (1970) suggestion that it should be possible to allow for errors due to guessing and forgetting on the part of subjects.

The Dayton and Macready model considers the probability of obtaining all possible response patterns for a postulated hierarchy under the assumption that the hierarchy is valid. For a valid hierarchy, only some of the possible response patterns are acceptable. This may be illustrated by reference to the following branched hierarchy containing five skills:



Whatever the configuration of the hierarchy, 32 (2^5) distinct response patterns are possible. However, only eight of these are true response patterns in that they would satisfy the implied hierarchical connections. The true response vectors may be represented by the following patterns, where "1" and "0" represent possession and nonpossession, respectively, of a skill and the skills are considered in the hypothesized sequence: (00000), (10000), (01000), (11000), (01100), (11100), (11110), (11111).

Using Dayton and Macready's notation, the probability of a subject producing a specific response pattern, "u", if the hierarchy is valid is given by:

$$P(u) = \sum_{j=1}^{q} P(u|v_j) \cdot \theta_j \qquad (1)$$

where v_j represents the set of "q" true response patterns and θ_j represents the probability that the "jth" true vector pattern occurs and

$$P(u|v_j) = \prod_{j=1}^{k} \alpha_i^{a_{ij}} (1-\alpha_i)^{b_{ij}} \beta_i^{c_{ij}} (1-\beta_i)^{d_{ij}} \qquad (2)$$

In Equation 2, α_i and β_i represent misclassification parameters. α_i represents the probability that a subject will produce a correct response to a skill which he or she should not be able to complete correctly if the hierarchy is valid. β_i represents the probability that a subject will produce an incorrect response to a skill which he or she should be able to complete correctly if the hierarchy is valid.

Equation 2 indicates the values of the misclassification parameters α_i and β_i are each raised to a power necessary to fit all "true" response patterns to an observed data vector. Similarly, $(1-\alpha_i)$ and $(1-\beta_i)$ are raised to the number of true responses in each case. The product of each of these terms over all possible response patterns represents Equation 2. Multiplying this by the probability that the jth true ~~pattern~~ vector occurs (θ_j), and summing this for all true pattern vectors (q) yields the probabilistic model represented by Equation 1.

Maximum likelihood estimates of the various parameters in the probabilistic model are obtained and these are used to compute the expected frequency of response for every response pattern possible. The goodness of fit between the data and the hypothesized hierarchy is then calculated by both a chi-square test and a likelihood ratio which is expressed in the form of a chi square.

The Dayton and Macready model requires a priori derivation of a hypothesized hierarchy. The hierarchy is accepted or rejected in its entirety; decisions regarding individual connections within the hierarchy cannot be made. However, it is possible to test different composite hierarchies involving the same skills to determine the hierarchy which is most consistent with the data.

In the following section, methods used in investigating transfer of learning in learning hierarchies are considered.

Methods of Testing for Transfer

White (1973) has identified several weaknesses in simple indices which have been derived to test for transfer of learning between skills. He indicates that Gagné's index of proportion positive transfer and others like it are not considered to be acceptable, for reasons previously discussed. Other investigators have acknowledged the importance of transfer, and have proposed methods to measure transfer. Resnick (1973) proposes that the most satisfactory means to test for positive transfer appears to be the direct comparison of randomly assigned groups of students, with one group taught according to a hypothesized hierarchical sequence, and the other in a non-hierarchical or deliberately scrambled sequence. Effects of the sequence of learning on the rate of individual learning of both individual tasks and the whole set of tasks can then be examined. Uprichard (1970) performed a transfer experiment of this type to determine the most efficient instructional sequence through which preschoolers acquire knowledge of "set" relations. Skills comprising the hierarchy were taught in all possible sequences, then the efficiency of a particular sequence was evaluated in terms of both the time required to learn the task to criterion and performance on a posttest consisting of both criterion and transfer items. This method could prove to be a very time consuming practice for hierarchies which contain many skills, where the number of alternative sequences would be great. It could prove useful, however, in investigating transfer within a small part of a hierarchy.

The preceding methods of investigating transfer may present an ethical question. If there is reason to believe that it is advantageous to be taught in the hypothesized hierarchical sequence, then teaching selected subjects in alternate sequences could represent a deliberate attempt to misinstruct them. Griffiths (1979, p. 191) proposes a method which eliminates this problem. He suggests that in order to test for transfer, two groups of subjects are required. One group would receive remedial instruction in accordance with the hierarchy, and would then be compared to a similar group which has not received remediation, in order to determine evidence of transfer.

Okey and Gagné (1970) employed another method to investigate transfer in a learning hierarchy. They compared two groups of students in which one group received instruction, and was then tested. Results of this testing were used to identify subordinate skills which were difficult for students. The second group of students received instruction which had been revised to help students overcome difficulties which had been identified for the first group. After comparing achievement for the two groups, Okey and Gagné (1970) concluded that the hierarchy promoted transfer of learning because the attainment of both the final task and subordinate skills was significantly greater for the second group. This method, however, does not provide means for testing specific transfer effects between skills.

White and Gagné (1974) propose that positive transfer may be investigated by selecting a psychometrically validated hierarchy and then, for each connection to be studied, obtaining two groups of learners who are ready to learn the lower skill. One group is taught the lower skill of the pair, and then the upper skill. The second group is taught only the upper skill. White and Gagné (1974) suggest that positive transfer is demonstrated if more of the first group acquire the superordinate skill, than those of the second group. They acknowledge that the practical application of this design may present some difficulty, as this would require substantial interference with normal classroom teaching. Presently there appear to be no published accounts of studies using this method.

Bergan (1980) has proposed the use of a structural analysis approach in testing for positive transfer. Structural analysis involves a consideration of several other variables, in addition to that of the attainment of prerequisite skills, in the study of the learning of higher-level skills. According to Bergan (1980), a structural equation model would show the relationships among exogenous variables determined by causes operating outside the model, endogenous variables determined by exogenous variables, and other endogenous variables within the model, as well as disturbances including all unspecified sources of variation affecting model variables but not explicitly identified in the model. A set of simultaneous equations based upon multiple regression techniques is used to describe these relationships. The coefficients within these equations provide an indication of the extent to which independent model variables mediate transfer with respect to dependent variables. The suggestion that other variables as well as prerequisite skills may be responsible for positive transfer between skills seems reasonable, however Griffiths (1983) has shown that it is possible to obtain significant path coefficients using this method, while obtaining low transfer values for the same data.

The method used in the present study to test for positive transfer was developed by Griffiths (1979, p. 196). This method is described in detail in the next chapter. It was selected for use in the present study because it is practical for research involving intact classes and is also suitable for hierarchies comprised of any number of skills.

The final section of this chapter presents several studies which investigate learning hierarchies in science and the application of hierarchy theory to other areas of educational research, including the study of students' misconceptions.

The Identification and Application of Hierarchies in Science Education

Since Gagné (1962) first used the term "hierarchy" in his theory of how human beings acquired complex skills and knowledge, there has been a continuing increase in the application of hierarchy theory to problems of instruction and evaluation. This section examines some current research on learning hierarchies in science and their application to science education.

The best known and most extensive attempt to apply Gagné's hierarchical model in science is 'Science-A Process Approach', or SAPA (1967), a science curriculum for children from kindergarten to grade six. This project consists of an integrated network of hundreds of skills leading to the development of important processes used in 'doing science'. Despite initial enthusiasm for the project, the cumulative level of success exhibited by students enrolled in the SAPA experimental classes was less than the authors had hoped (Griffiths, 1979, p. 79). Indeed, Gagné (1973, p. 25) has commented that the SAPA learning hierarchy is not a learning hierarchy at all because the instructional units involved are entire lessons and the contents of individual lessons were not designed as learning hierarchies.

Other applications of the learning hierarchy model have dealt with smaller units of content leading to the acquisition of science concepts. Okey and Gagné's (1970) hierarchy concerning solubility product problems, White's (1974a) hierarchy relating to kinematics, Linke's (1975) hierarchy concerning graphical skills, Beeson's (1977, 1981) hierarchy on electrical skills, Griffiths' (1979) hierarchy involving the mole concept in chemistry, Whelan's (1982) hierarchy dealing with stoichiometric calculations and Pottle's (1982) hierarchy concerning the conservation of mechanical energy all relate to content expected to be covered in several class periods.

Some early attempts to investigate learning hierarchies in science (Merrill, 1965; Kolb, 1967; Raven, 1967; Okey, 1968; Olsen, 1968; Capie & Jones, 1971) have been criticized for reasons of faulty experimental design as well as weak statistical procedures (White, 1973; Griffiths, 1979). Such studies have been omitted from the present review, as the significance of their findings have been marred by research flaws.

The majority of studies relating to learning hierarchies have dealt with mathematics and science skills, with the emphasis much more towards mathematics. A review of the literature indicates few well-established learning hierarchies exist in the area of science, and those that do often contain a substantial proportion of mathematics skills. Indeed, not one published study could be found which investigated a learning hierarchy dealing with a biology concept. A study by Baird and White (1982) makes reference to a learning hierarchy dealing with genetics, however the hierarchy is not presented, nor is a source which includes this hierarchy cited. Upon determining the topic of water potential in plant cells as an area of student difficulty in biology, Johnstone and Mahmoud (1980b) analyzed the concept of water potential in plants by performing a Gagné-type analysis. However, the authors clearly indicate that they did not produce a learning hierarchy for this concept, but rather a "network which linked the ideas together" (Johnstone & Mahmoud, 1980b, p. 325). Despite the call for research dealing with hierarchies in areas other than physical science (White, 1974b; White & Gagné, 1974; Beeson, 1977), there appears to be a lack of such studies.

Beeson (1977) has addressed the need to test the concept of learning hierarchies to nonmathematical areas of the science curriculum. He constructed a hierarchy leading to the determination of quantities in electric circuits. The sample used in the study consisted of 166 grade ten students from five coeducational metropolitan Australian high schools. In discussing the results of the study, Beeson (1977) suggests his work provides further support for the distinction between intellectual skills and verbal information elements in learning hierarchies, in addition to demonstrating the application of the learning hierarchy model to an area involving some nonmathematical learning. Several aspects of Beeson's study require further consideration, however. In light of strong support for the exclusion of verbal information from learning hierarchies and the exclusive use of hierarchies to represent relationships between intellectual skills on the part of both Gagné (1972) and White (1974c), there remains some question as to the need for further investigation of the role of verbal information in hierarchies. However, Beeson (1977) indicates his intention to investigate the distinction between the place of intellectual skills and verbal information elements within a learning hierarchy for a topic involving a substantial amount of nonmathematical learning. Of the 17 intellectual skills comprising the hypothesized hierarchy, five are mathematical skills. As almost one-third of the skills comprising the hierarchy are mathematical skills, it is questionable whether this can be considered a topic involving a "substantial" amount of nonmathematical learning. In addition, Beeson utilized the White and Clark (1973) test to test only those connections which did not involve verbal information elements. Only one item was used to test each verbal information element of the hierarchy because Beeson (1977, p. 122) claims there was "no point in asking two questions in such cases because the only way to do so would be to ask the same question twice."

This claim seems rather unreasonable as verbal information is often tested by more than one form of test item (Bloom, 1956; Hedges, 1966; Hopkins & Stanley, 1981), suggesting that it is not so impossible to prepare two parallel, but nonidentical, test items for verbal elements of the hierarchy. Secondly, because the relationship between verbal information units and intellectual skills was a major investigative focus of the study, it appears quite inappropriate to determine the validity of connections involving verbal elements by a subjective decision, while connections between intellectual skills are determined using the White and Clark (1973) test. Further, Trembath and White (1979) advise that if a student is tested on only one item to determine mastery, they might have mastered the skill, but could well have achieved only a chance success or superficial attainment. Beeson did not provide a description of the procedure used in subjectively determining the validity of hierarchical connections.

A diagram of the final, validated form of the hierarchy emerging from Beeson's (1977) study was not provided, although the hypothesized hierarchy was presented and validation results were indicated. A validated form of the hierarchy was presented in a later paper (Beeson, 1981); however several connections which were included in the hypothesized hierarchy were removed from the final form without having been tested. As a result, it appears that further research is required before valid claims may be made for this particular hierarchy in electrical science and for nonmathematical hierarchies in general.

A significant aspect of learning hierarchy research has been noted by Beeson (1981): most research has focused upon hierarchy validation, with relatively little attention to the quality of learning achieved. In considering the latter, he raises a significant concern, supported by evidence in the literature, that students may tend to learn intellectual skills comprising a hierarchy in a mechanical way, rather than a meaningful way. Beeson suggests that the mechanical learning of skills may result from several factors: teaching the skills in a relatively isolated manner, such that students are unable to understand how to combine skills already learned in order to master higher-order skills; lack of a sufficiently elaborate context of verbal instructions, preventing the learner from fully comprehending the nature of learning objectives; inability on the part of the learner to recall relevant subordinate skills at the appropriate time.

Upon consideration of Ausubel's theory of meaningful learning (Ausubel, 1963; Ausubel et al., 1978), Beeson (1981) proposed that if the learning of a hierarchy of intellectual skills occurred within a context of meaningful knowledge about a relevant anchoring idea, this would facilitate meaningful learning. He investigated this idea with a sample of 188 grade ten students who were taught a hierarchy involving electrical science skills, prepared in an earlier study (Beeson, 1977). The students were divided into three groups and taught in one of three different contexts: "isolated elements", in which the elements of the hierarchy were taught in isolation; "verbal instructions", in which the types of verbal instruction specified by Gagné (1962) were provided; and "anchoring idea", in which the elements of the hierarchy were taught in relation to a relevant anchoring idea (Ausubel, 1968). Following instruction, students were tested after an interval of approximately two days and again after an interval of seven weeks, in order to measure long and short-term achievement of the terminal skill, lateral transfer and subordinate skills, respectively. Beeson found that the "anchoring idea" group did significantly better ($p < .005$) on the short-term test of lateral transfer than the other groups. However, these results did not persist after seven weeks. The same group did significantly better ($p < .01$) on the test of achievement of the final task in the long term. However there was no significant difference between groups on the short-term achievement of this task. There was no significant difference among the three groups in either the short-term or long-term test of achievement of subordinate skills.

The results of the study support Beeson's prediction that when students learn a hierarchy of intellectual skills in the context of an anchoring idea, more meaningful learning results. Important implications for teaching arise from these findings. Beeson's (1981) study offers strong support that the context in which skills are learned is an important factor affecting meaningful learning. In addition, the study provides evidence that students may learn intellectual skills in a mechanical rather than a meaningful way.

In focusing upon the quality of learning achieved in learning hierarchy studies, Beeson's (1981) study has revealed some important considerations for hierarchy research. White and Gagné (1974) have described the end purpose of research into hierarchies as 'better learning than is currently achieved'. Beeson's work has provided some direction toward attaining this goal.

Several researchers have investigated the application of Gagné's learning hierarchy model to other areas of educational research. One such area is mastery learning. In a recent study, Trembath and

White (1979) used a hierarchy dealing with kinematics (White, 1974c) to investigate whether mastery learning could be improved through the use of instruction based upon a validated learning hierarchy. They found that it was highly effective to present tasks in a sequence which was consistent with the requirements of the hierarchy, and to require learners to clearly demonstrate achievement of each task before being allowed to proceed to the next. The results of Trembath and White's (1979) study imply that mastery learning strategies may be improved if validated learning hierarchies are used to sequence learning materials intended for the teaching of intellectual skills. They also indicate an important consideration for learning hierarchy research: that improved performance on hierarchically related tasks resulted from requiring learners to demonstrate a high level of mastery of subordinate elements during instruction.

Research into learning hierarchies also appears to have important implications for instructional development (Resnick, Wang & Kaplan, 1973; Gagné & Briggs, 1974; Dick & Carey, 1978; Reid, 1981). Several learning hierarchy studies involving science concepts have studied the application of the learning hierarchy model to this area. Using a hierarchy dealing with solubility product problems, Okey and Gagné (1970) investigated the application of their learning hierarchy to diagnose weaknesses in a unit of instruction on this topic. They proposed that data obtained from testing skills comprising a learning hierarchy could be used to identify areas of student difficulty for this topic. Then, having identified areas of student difficulty, the instructional unit would be revised in an effort to improve student performance in these areas. Unfortunately, several weaknesses are apparent in Okey and Gagne's study. The skills comprising the solubility learning hierarchy were not described precisely; and because the percentage of individuals successfully completing certain subordinate skills was quite low, even after remediation, it is possible that the hierarchy may be less valid than the encouraging results of their study suggest. Nevertheless, the use of the diagnostic capability of hierarchies represents a promising application of hierarchy theory.

Interest demonstrated by instructional developers in learning hierarchies goes beyond their use as a tool for identifying weak areas in existing instructional materials. In particular, learning hierarchies may be useful in the development of new materials, where the material to be learned involves intellectual skills. Trembath and White (1979) have identified several attributes of learning hierarchies which make them especially attractive to instructional developers. In particular, they note a hierarchy contains only relevant skills, and the sequence of instruction is clear. In addition, students should be able to understand instruction associated with a given hierarchy because, by design, at every step it builds upon what they are able to do and moves them on a small step further. Also, if instruction is based upon a hierarchy, it is possible to have a diagnostic test for each skill as an integral part of that instruction.

From the perspective of an instructional developer, Reid (1981) strongly supports the use of learning hierarchies in instructional development. However, he notes that there is no catalogue of validated hierarchies which is available to instructional developers. As a result, they are forced to generate their own hierarchies for instructional design purposes. Since many important and costly decisions depend upon the validity of the hierarchy used, the developer must make some attempt to assure its validity. Unfortunately, advances in hierarchy validation techniques which have been presented in the literature do not appear to provide a solution to the instructional developer seeking practical validation procedures (Reid, 1981). Rather, current research literature appears to be moving toward more tedious methods of validation in an attempt to evoke more conclusive support for the model.

In an attempt to encourage greater application of learning hierarchy theory to instructional development, White and Gagné (1978) proposed that when hierarchies are viewed as tools for instructional planning, rather than as instruments for research purposes, it would be reasonable to sacrifice some degree of precision for practicality. They perceive the collection of empirical data pertaining to a learning hierarchy as a formative evaluation procedure. On the basis of empirical data, decisions can be made regarding revision of the hierarchy itself, of the teaching conducted according to its plan, or of the testing of skills involved. Therefore, using a previously validated kinematics hierarchy (White, 1974c), White and Gagné (1978) proposed a validation method for use by instructional developers which was not excessively complicated and time-consuming. Upon comparing their results with more complex validation data for the same hierarchy, White and Gagné suggest that their simplified validation procedure is of sufficient accuracy for purposes of formative evaluation of instructional materials. However, they caution that when research efforts are being served, more stringent hierarchy validation methods should be applied.

Further support for the simplification of hierarchy validation procedures for purposes of instructional development is presented by Dick (1980). He advocates even further simplification of the procedure described by White and Gagné (1978) to that of simply determining the percentage of students who have mastered each skill of the hierarchy. However, this method would appear to provide a measure of relative difficulty of skills, rather than a measure of hierarchical dependence.

It is the view of this investigator that the solution to the problem of hierarchy validation in instructional development does not lie in partially diminishing the effort required in validation; but rather in removing this process from among the duties of an instructional developer. There is a need for the provision and cataloguing of learning hierarchies to be used by instructional developers. Until such a pool of validated hierarchies becomes available, it seems reasonable to invest the time and effort required for rigorous validation procedures, rather than developing instructional materials based upon a learning hierarchy which may have dubious validity.

The Application of Learning Hierarchy Theory in the Study of Students' Misconceptions

The learning hierarchy model may be potentially useful in yet another area of educational research: the study of students' misconceptions of important science concepts. Studies of students' conceptual errors in science have a long history; the literature indicates research in this area has spanned no less than four decades (Hancock, 1940; Bailey, 1962; Weaver, 1965; Doran, 1972; Brumby, 1979; Helm, 1980; Simpson & Arnold, 1982). Recently, interest in students' science misconceptions has been revived and many new studies have emerged. This renewed interest parallels a trend observed by Simpson and Arnold (1982, p. 174):

> There is however a growing recognition that it is not merely the absence of appropriate mental operations, concepts or skills which inhibits learning; the presence of previously acquired theories, information or skills which may be incorrect or inappropriately applied may actively interfere with the acquisition of new material.

Different forms of prior "incorrect knowledge" have been distinguished. "Alternative frameworks" (Driver & Easley, 1978) are said to arise as a result of students' experience with natural events and their attempt to make sense of them, prior to formal instruction in the classroom. They result when students formulate ideas which are clearly erroneous, in order to explain these events. "Misconceptions" occur as students are exposed to models and theories during formal instruction; as students attempt to relate this new knowledge to existing knowledge, wrong connections are made and misconceptions result. Simpson and Arnold (1982) distinguish two types of misconception. Students may assimilate material which is formally taught into existing alternative frameworks, or they may form meaningful but inappropriate linkages between true pieces of information, resulting in an incorrect concept.

There is much support in the literature for the investigation of students' misconceptions and alternative frameworks. Nussbaum (1981) urges that the diagnosis of students' misconceptions and the identification of reasons for such misconceptions is a prerequisite for helping students to develop correct scientific conceptions. He maintains that difficulties which students experience in comprehending and internalizing certain concepts could be avoided if teachers could understand the nature of their misconceptions and in turn make constructive use of this knowledge on the students' behalf. Finley and Stewart (1982) urge that research to identify prior knowledge of students with respect to commonly taught content areas would provide valuable information for curriculum developers, as well as teachers. In this way, curriculum and instruction could be planned to include missing knowledge and to correct common misconceptions. This view is echoed by other investigators. Deadman and Kelly (1978) advocate the investigation of students' prior understanding, or misunderstanding of a topic before the development of instruction. Likewise, Brumby (1979) suggests it is important to identify students' misconceptions of a given concept, and to plan instruction to overcome misconceptions which appear to block their understanding of basic concepts.

This interest in misconceptions which relate to single concepts is a relatively recent one. In early studies, researchers investigated misconceptions which dealt with science in general. Concepts from a variety of science disciplines were tested to assess the extent to which general science misconceptions were held (Bailey, 1962; Kuethe, 1963). In some cases, fallacies involving myths and superstitions, such as "a snake never dies until sundown" (Kuethe, 1963, p. 361) were included in lists of prevalent misconceptions. More recently there has been a trend toward the investigation of misconceptions relating to specific concepts. Doran (1972) investigated misconceptions relative to the particulate nature of matter held by secondary school students. Nussbaum and Novak (1976) identified children's conceptions and misconceptions about the earth. Johnstone, Macdonald and Webb (1977) identified misconceptions prevalent among students studying the concept of dynamic equilibrium. Erickson (1979) reported a range of alternative conceptions of the concepts of heat and temperature held by 12-year-old children. Others have focused upon misconceptions concerning the concepts of "chemical equilibrium" (Wheeler & Kass, 1978), "elementary dynamics" (Viennot, 1979), "light" (Stead & Osbourne, 1980), "gravity" (Gunstone & White, 1981) and "life" (Brumby, 1982).

Often, teachers do not appear to be aware of students' misconceptions. Johnstone et al. (1977) discovered cases in which misconceptions evolved during lessons which teachers perceived as perfectly lucid instructional presentations. Hart (1979) observed that while mathematics teachers believed that the methods of solution presented in class were those used by pupils in the successful completion of simple mathematics problems, many pupils were ignoring taught algorithms and employing their own methods, which had a limited application. Likewise, Simpson and Arnold (1982) reported that although teachers were aware of some student difficulties concerning biology concepts, the precise nature and extent of students' misconceptions and alternative frameworks were not generally appreciated. They attribute this to the fact that standard classroom tests do not normally include questions relating to peculiar and erroneous information held to be true by students. Simpson and Arnold (1982) suggest these tests are constructed on the basis that students can only know what they have been formally taught and accordingly tend to assess only the extent of retention of classroom-based learning.

Johnstone et al. (1977) emphasize the need to identify and make teachers aware of potential misconceptions which students hold, to enable them to teach consciously toward helping students make correct connections of new knowledge with their existing knowledge, and to warn students against wrong connections. Nussbaum (1981) recommends that the development of appropriate skills for the diagnosis of student misconceptions should be a primary concern for every teacher-training program. He urges that it is necessary to develop an awareness in teachers that it is not enough to evaluate a student's answers in terms of scientific correctness, but that it is of equal importance to pay attention to the nature of the student's misconceptions.

The task of dealing with students' incorrect conceptions in science is not an easy one, especially if they develop when students encounter a concept prior to its introduction in the classroom. Alternative frameworks, and misconceptions in which students assimilate new material into existing alternative frameworks, may develop psychological meaning and hence become quite resistant to extinction (Simpson & Arnold, 1982). In his investigations, Lebouter-Barrell (1976) discovered that in order to justify a false intuitive belief, students often used precise but irrelevant scientific knowledge. Even in the case of concepts taken from subject areas in which one would imagine students have very little knowledge prior to instruction, Viennot (1979, p. 205) advises:

> . . . we all show a common explanatory scheme . . . which, although we were not taught it at school, represents a common and self-consistent stock of concepts and which, however wrong it may be, resists attempts to change or modify it.

While investigating secondary school boys' knowledge of evolution and heredity prior to formal teaching of these topics, Deadman and Kelly (1978) found that most interpreted evolution in what appeared to be naturalistic or Lamarckian terms.

Researchers have used various formats to identify student misconceptions. Some investigations have been conducted in an interview format in which students answer questions or think aloud while solving problems (Nussbaum & Novak, 1976; Erickson, 1979; Stead & Osbourne, 1980). Because of the long period of time required to analyze such data, only small numbers of students are used. In other studies, structured-response tests have been applied to large samples. In such cases, the advantages of obtaining detailed interview data is sacrificed in favour of obtaining qualitative information from a large sample. This technique was used by Doran (1972), Macdonald et al. (1977), Johnstone and Mughol (1978) and Helm (1980). Other investigators (Warren, 1971, 1976; Viennot, 1979) have used free response tests and interviews with considerable success. Helm (1980) is quick to state that one method does not necessarily constitute the best way of establishing the existence of misconceptions among students, or the firmness with which they are held. He emphasizes the need for more information concerning students' science misconceptions, obtained by a variety of means. The learning hierarchy model may offer a useful alternative for the study of misconceptions involving concepts represented by intellectual skills.

Alternative frameworks, and misconceptions involving alternative frameworks, appear to be quite resistant to teacher intervention. However, another class of misconceptions, those relative to narrowly-defined concepts typically first encountered in formal instruction, may be relatively amenable to correction. It is in the study of this type of misconception that the learning hierarchy model may be applicable. Learning hierarchies deal with concepts represented by intellectual skills. They tend to be narrowly defined in terms of specific operations and are typically encountered for the first time in school learning. Simpson and Arnold (1982) stress that misconceptions are likely to be highly specific, and warn they may perhaps only be discovered by detailed investigation of individual topic areas. Classroom testing often focuses upon the evaluation of students' attainment of a particular skill representing the target skill in a unit of instruction. When several other skills are necessary prerequisites of this target skill, an analysis of items which test only the target skill may not reveal all underlying misconceptions. In the case of weaker students who may not be able to attempt items testing complex skills, the teacher is left without any clues as to where a given student's difficulties may lie. On the other hand, the learning hierarchy model involves an analysis of a given target skill into a network of subordinate skills, followed by the testing of each skill comprising the hierarchy. As a result, every subordinate skill may be analyzed for misconceptions individually and misconceptions may be revealed which would not have been apparent from an analysis of the target skill alone. This process could enable a teacher to pinpoint the source of a student's inability to achieve a given skill in a way that standard classroom testing measures do not.

Upon considering the role of teachers in dealing with students' misconceptions, Helm (1980) suggests that if the origin of a misconception can be identified, a teacher may be able to help students overcome this misconception. He observes that in certain cases, plausible hypotheses for misconceptions may suggest themselves quite readily; however Helm (1980) advises that while these guesses may be correct, it would be desirable to obtain some quantitative information regarding misconceptions which would enable them to be identified more precisely.

This might provide some insight into the nature of specific misconceptions. Data obtained from hierarchy validation procedures could provide quantitative information concerning misconceptions. In addition, through the use of open-response items in the testing of hypothesized subordinate skills, misconceptions which may not have occurred to teachers and other experts are revealed.

Johnstone et al. (1977) stress that a teacher requires adequate feedback in order to detect misconceptions. However, in an investigation of pupils' knowledge of photosynthesis, Simpson and Arnold (1982) indicate that concepts which are wrong but which are nevertheless meaningful to the learner may escape detection by typical methods of classroom testing. Test instruments which have been developed according to a learning hierarchy are capable of providing this needed feedback in a more detailed and efficient way than standard tests tend to.

From the preceding discussion, it is apparent that the ability to identify problems encountered by students in the learning of intellectual skills by identifying misconceptions of related subordinate skills, represents a potentially important application of the learning hierarchy model.

In the next chapter, the design of the study and a description of test instruments and procedures are presented.

Chapter 3

DESIGN, INSTRUMENTATION AND PROCEDURES

Introduction

The process of developing a learning hierarchy generally involves a series of distinct, yet interdependent, stages. These include the specification and statement of the desired terminal skill, the generation of a hypothesized hierarchy for this skill, the development of test instruments for the hierarchy, the development of an instructional program, application of the test instruments and instructional program to an appropriate sample and analysis of the experimental data.

Upon identifying weaknesses in the methodology of early hierarchy studies, White (1974c) prepared a set of guidelines to eliminate potential weaknesses in the development and validation of learning hierarchies. These guidelines were accommodated in the present study. The sections to follow describe the development of the learning hierarchy which was used in the present study.

Statement of the Terminal Skill

As indicated in Chapter 1, a fundamental reason for requiring high school biology students to learn the concept of a food web is to enable them to understand how a phenomenon which drastically alters one population will ultimately affect another population in the same community. Expressed in behavioural terms in accordance with White's

(1974c) recommendation, the terminal skill of the food web hierarchy was defined as:

> Given a food web diagram, determine the effect of a sudden size change in one population on a second population which is not on the same food chain, when the effect may be transmitted along more than one route.

In specifying that the two populations are not part of a common food chain, the skill requires that subjects realize that all populations in a food web affect each other, regardless of their location in the web. Subjects must recognize implicit relationships which exist in the web and not treat the problem as a simple food chain problem. In specifying that the populations in question be located such that an effect passing from one to the other is transmitted along more than one route, the skill requires that subjects understand that effects of a change in one population may be passed to another along several different pathways, resulting in the production of a net effect.

The preceding specifications establish lower bounds with respect to both the complexity and the number of subordinate skills required for the terminal skill. In the present study, it is implied that the skill as stated may be applied to all situations which adhere to these specifications. This encompasses a variety of situations, ranging in difficulty according to the size and complexity of the food web to which the skill is applied.

A food web is a model, a simplified representation of feeding relationships in a given community. The more realistically the model mirrors nature, the more complex it becomes. The process of determining how an unusual increase or decrease in one population will affect another population in a real life situation is an onerous, if not impossible, task. In much the same way, complex food web diagrams present an arduous task to anyone attempting to determine the net effect of a change in one part of a food web on another. The exercise becomes one of frustration in attempting to untangle endless numbers of pathways. Surprisingly, students are occasionally presented with such tasks. A typical example may be found in a popular biology text (BSCS, 1970, p. 79). In the present study, subjects were not required to consider food webs involving more than four routes between populations in question. It was felt that increasing the complexity of food webs beyond this level would only increase the tediousness of the task, without demanding greater understanding of the basic skill.

Generation of the Hypothesized Hierarchy

After specifying the terminal skill in behavioural terms, the hypothesized hierarchy was derived using the task analysis procedure proposed by Gagné (1962). Analysis of the terminal skill was begun by asking the question, "What would the individual already have to know how to do in order to learn this new capability, simply by being given verbal instructions?" (Gagné, 1968, p. 3). Application of this question yielded other, lower-level, skills which were considered to be prerequisite to the terminal skills. Care was taken to describe each prerequisite skill thus identified in terms of representative observable performances which would indicate attainment of the skill by the learner. The question was then applied to each of the subordinate skills, in order to identify skills which were subordinate to each of these. The successive application of this method of task analysis to each newly identified task resulted in the development of a hierarchical sequence of subordinate skills hypothesized to be necessary for the acquisition of the terminal skill. The analysis terminated at a level in which skills were generated which described behaviours assumed to be available to the learner population at the beginning of the instructional period.

This hierarchy was considered by a group consisting of a science educator, a biology professor, a research assistant who had recent experience as a biology teacher, and the researcher who is a biology teacher.

It is important to note that several hierarchies were produced before one was achieved which appeared to be complete and ready for piloting. In view of the systematic nature of the task analysis procedure, it may seem unusual that careful application of Gagné's question to the terminal skill did not produce a suitable hierarchy initially. Yet this is not as peculiar as one might first assume. Reports of studies in which hierarchies were developed tend to promote false expectations of the simplicity of the task analysis procedure. In most cases there is no mention of intermediate hierarchies which were amended to a form which would then be validated. Accurate answers to the question, "What must the learner be able to do in order to learn this new skill?" do not arise easily. When applying the question to a given skill, the response may be too general, incorporating more than one skill. White (1974c) advises that once the elements of a hierarchy have been identified, the researcher should invent and consider possible divisions of these elements. In this way, the precise definitions of skills become apparent. This process could change the structure of the original hierarchy by increasing the number of elements and connections.

In the present study, one element initially required that subjects be able to determine the effect of a change in the size of a prey population, on its predator population. It was decided to divide the original skill into two skills, suggesting that to determine the effect of an increase in a prey population was different than determining the effect of a decrease in that prey population on its predator. Similar divisions of skills were made throughout the hierarchy. Upon piloting the hierarchy, the data indicated that many of the divisions did not appear to represent different skills. This resulted in another change in the structure of the hypothesized hierarchy.

Another complication may occur when answers to Gagné's question are biased as a result of consideration of traditional teaching sequences. Certain skills may be perceived as necessary prerequisites of other skills because, traditionally, textbooks or curricula tend to sequence the former before the latter; even when there is not necessarily a reason, with respect to the logic of the subject matter, for doing this. Upon inspection of the hierarchy by others, these relationships may be discovered and corrected, amending the hierarchical structure once again. In the present study, it was assumed that subjects must first be able to solve word problems involving predator-prey relationships before they could solve similar problems based on food web diagrams; and that subjects must first be able to deal with predator-prey relationships on simple food chain diagrams before attempting similar problems on food web diagrams. In both cases, these assumptions were not based on traditional teaching sequences; however upon piloting the hierarchy, the data indicated that these assumptions were not supported.

It seems appropriate at this point to outline some practical suggestions concerning the task analysis procedure. First, it is important to refrain from using course objectives or existing teaching programs as initial references in task analysis. A suitable statement of the terminal skill to be learned and Gagné's question should be one's only tools. This will help eliminate the bias described earlier, which leads one to incorrectly perceive hierarchical relationships where none exist. Second, care must be taken to ensure that each skill derived from asking Gagné's question represents only one element and that this element must represent an intellectual skill. It is good practice to produce a sample test item to represent the skill, after stating the skill. This exercise will help to indicate whether the element represents one skill and whether this is an intellectual skill. Finally, it is important to include all reasonable skills and connections, as suggested by White (1974c); validation procedures may eliminate connections, but cannot produce necessary skills and connections which were omitted from the beginning.

Once a hierarchy was produced which was suitable for piloting, a pilot study was carried out with 37 subjects from two grade ten biology classes from a St. John's school. These subjects did not take part in the main study. As indicated previously, results of the pilot study indicated the need for amendments to the structure of the hierarchy. When these changes were made, the hierarchy was again scrutinized by a team of experts, and was then finally approved for the validation stage.

Application of the task analysis procedure described above, followed by modification after the pilot study, led to the identification of nine skills. A description and illustrative example of each skill follows (each skill is illustrated by reference to the food web shown in Figure 3):

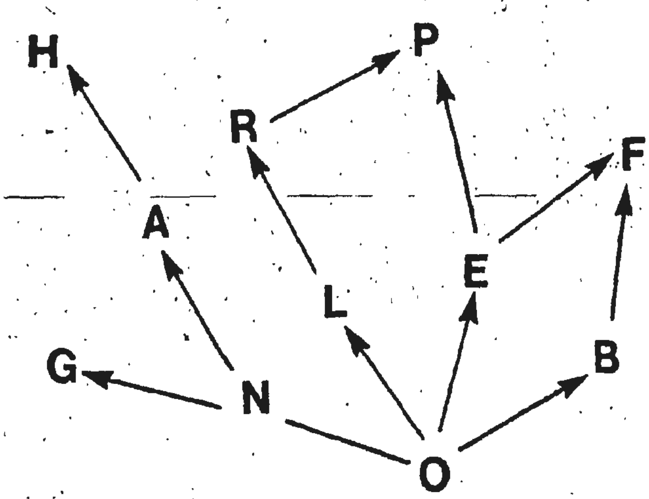


Figure 3. A sample food web to illustrate the skills of the hypothesized hierarchy.

Skill 9: Given a food web diagram, determine the effect of a sudden size change in one population on a second population which is not on the same food chain, when the effect may be transmitted along more than one route.

For example, "determine the effect of a sudden increase in population F on the size of population R" (Figure 3).

Skill 8: Given a food web diagram, determine the effect of a sudden size change in one population on a second, nonadjacent, population located lower on the same food chain, when the effect is transmitted along more than one route.

For example, "determine the effect of a sudden decrease in population P on the size of population L" (Figure 3).

Skill 7: Given a food web diagram, determine the effect of a sudden size change in one population on a second, nonadjacent, population located higher on the same food chain, when the effect is transmitted along more than one route.

For example, "determine the effect of a sudden increase in population L on the size of population P" (Figure 3).

Skill 6: Given a food web diagram, indicate all possible pathways through which the effect of a change in one population is transmitted to a second population.

For example, "circle the letters indicating populations through which the effect of a change in population L is passed on to population P" (Figure 3).

Skill 5: Given a food web diagram, determine the effect of a sudden size change in one population on a second, nonadjacent, population located lower on the same food chain, when the effect is transmitted along only one route.

For example, "determine the effect of a sudden decrease in population H on the size of population N" (Figure 3).

Skill 4: Given a food web diagram, determine the effect of a sudden size change in one population on a second population, not located on the same chain, when the effect is transmitted along only one route.

For example, "determine the effect of a sudden increase in population G on the size of population A" (Figure 3).

Skill 3: Given a food web diagram, determine the effect of a sudden size change in one population on a second, nonadjacent, population located higher on the same food chain, when the effect is transmitted along only one route.

For example, "determine the effect of a sudden decrease in population N on the size of population H" (Figure 3).

Skill 2: Given a food web diagram, determine the effect of a sudden size change in a predator population on its prey population.

For example, "determine the effect of a sudden increase in population G on the size of population N" (Figure 3).

Skill 1: Given a food web diagram, determine the effect of a sudden size change in prey population on its predator population.

For example, "determine the effect of a sudden decrease in population N on the size of population G" (Figure 3).

The relationships among Skills 1 to 9, in their hypothesized hierarchical arrangement, are shown in Figure 4. The sequence of development of the intellectual skills which comprise the hierarchy is consistent with Gagné (1970) in that Skills 1, 2 and 6 represent the development of discriminations and concepts, while Skills 3, 4 and 5 represent the direct application of rules relating to these concepts and Skills 7, 8 and 9 represent the use of combinations of these rules, which is the use of higher order rules.

In the following sections, the procedures which were followed to determine the validity of the hypothesized hierarchy are described. These involve the application of appropriate instructional and testing procedures to a sample, and methods for the analysis of the data from this sample.

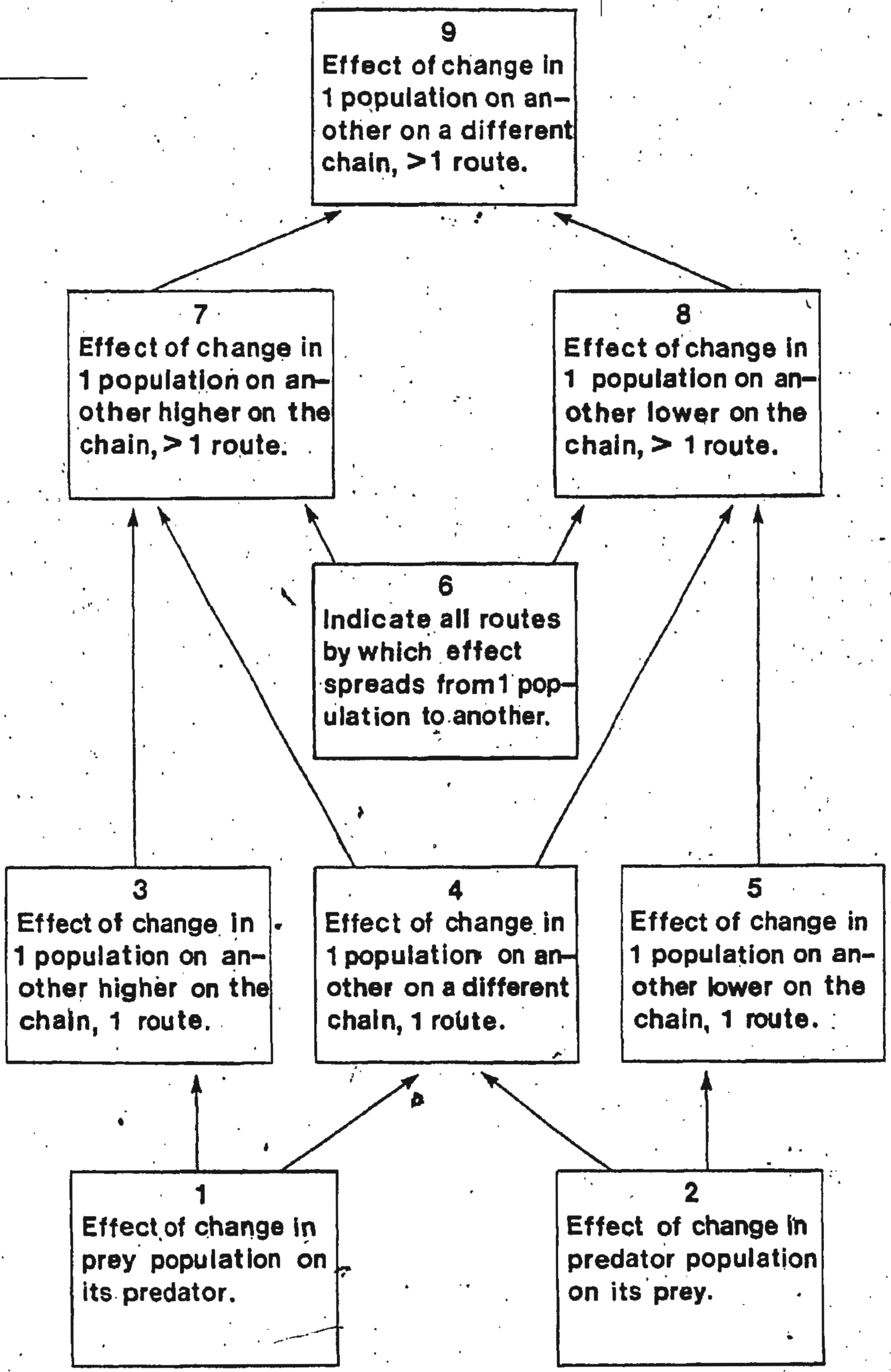


Figure 4. The hypothesized food web hierarchy.
Note: ">" signifies "more than."

Sample

The sample consisted of 200 grade ten biology students from three high schools in the St. John's area. Eight coeducational classes and three teachers were involved. The students represented a variety of socioeconomic backgrounds. All classes studied the same biology curriculum (Government of Newfoundland and Labrador High School Biology Curriculum Guide, 1979) and used the same text book (Oram, Hummer & Smoot, 1979).

Procedure

The initial step in the experimental design occurred as part of the regular classroom instruction of the students in the sample. The study began with the subjects receiving instruction on food webs from their biology teacher. No attempt was made to interfere with the preferred instructional practices of the teachers involved, which in each case could best be characterized as conventional, involving mainly teacher exposition. As the structure of a learning hierarchy should be independent of instructional mode (Gagné, 1973, p. 21), it was felt that this practice would not detract from the internal validity of the study and would tend to promote greater external validity than would use of an approach designated by the researcher. Because instruction took the form of regular classroom instruction, the study was scheduled to coincide with the teaching of food webs in the classroom, and selection of schools was somewhat limited to those studying food webs at a certain time. The three schools from which the sample was taken were studying the topic at approximately the same time, and all students had studied some basic ecological concepts prior to studying food webs. All three schools had class periods of 40 minute duration.

Following instruction on food webs, the subjects were tested on the skills comprising the hypothesized food web hierarchy during one class period. Because this test preceded remediation in the experimental design, it was called the "pretest." The pretests were corrected and two days later subjects were presented with remedial booklets. Each subject was given an individual prescription for particular skills from the remedial booklet for which both items testing the skill were not answered correctly, or were not completed by the particular subject. All subjects received booklets, however the number of skills to be remediated in each case varied. Subjects were informed they would be retested and were asked to complete all remedial work as homework by the second test date. Subjects were also informed that the remedial booklets would be collected at that time and returned at the end of the study.

Three days after receiving the remedial booklets, students were posttested using a parallel form of ~~the~~ pretest. Whether they gained skills which were not mastered on the pretest was tested by determining the mastery of skills on the posttest. These data were used to test for transfer of learning from subordinate to superordinate skills. The method of testing for transfer was developed by Griffiths (1979, p. 196). It investigates the relationship of gain of subordinate skills between the food web pretest and the food web posttest, and gain of related superordinate skills in the food web posttest. The following steps were involved in this part of the analysis:

1. Those skills in the hypothesized hierarchy which were directly subordinate to any other skill(s) in the hierarchy were identified. The steps which follow refer to each subordinate-superordinate skill connection.

2. Following regular instruction, those subjects who failed both skills in a particular connection were identified. This group formed the subsample for each connection under test. The size of this subsample varied for different hypothesized connections.

3. Following remediation on those skills which were failed in the initial testing, students were retested on all skills.

4. Those subjects in each subsample who gained the subordinate skill of the connection under test were identified; as well as those who failed to gain the subordinate skill. These subjects were designated "gain" and "no gain", respectively.

5. Subjects within the "gain" and "no gain" groups were further classified with respect to their performance on the superordinate skill of the connection under test. These subjects were designated either "pass" or "fail."

6. The significance of the relationship between Gain/No Gain and Pass/Fail was determined for each connection by application of a chi-square test with one degree of freedom in each case.

The tests and remedial booklet are described in the sections to follow. The actual pretest, posttest and remedial booklet appear in appendices A, B and C, respectively. The experimental design of the study is illustrated in Figure 5.

Instruments

Two tests were administered in this study, namely the food web pretest and the food web posttest. For each element of the hypothesized hierarchy, a minimum of two equivalent test questions was required for the hierarchy validation procedure. To avoid spurious results for items occurring later in the test, it is necessary that all subjects have adequate time to attempt all items. Hence, the maximum number of test items per element was limited by the available testing time. In the present study, to ensure sufficient time to administer the test and to

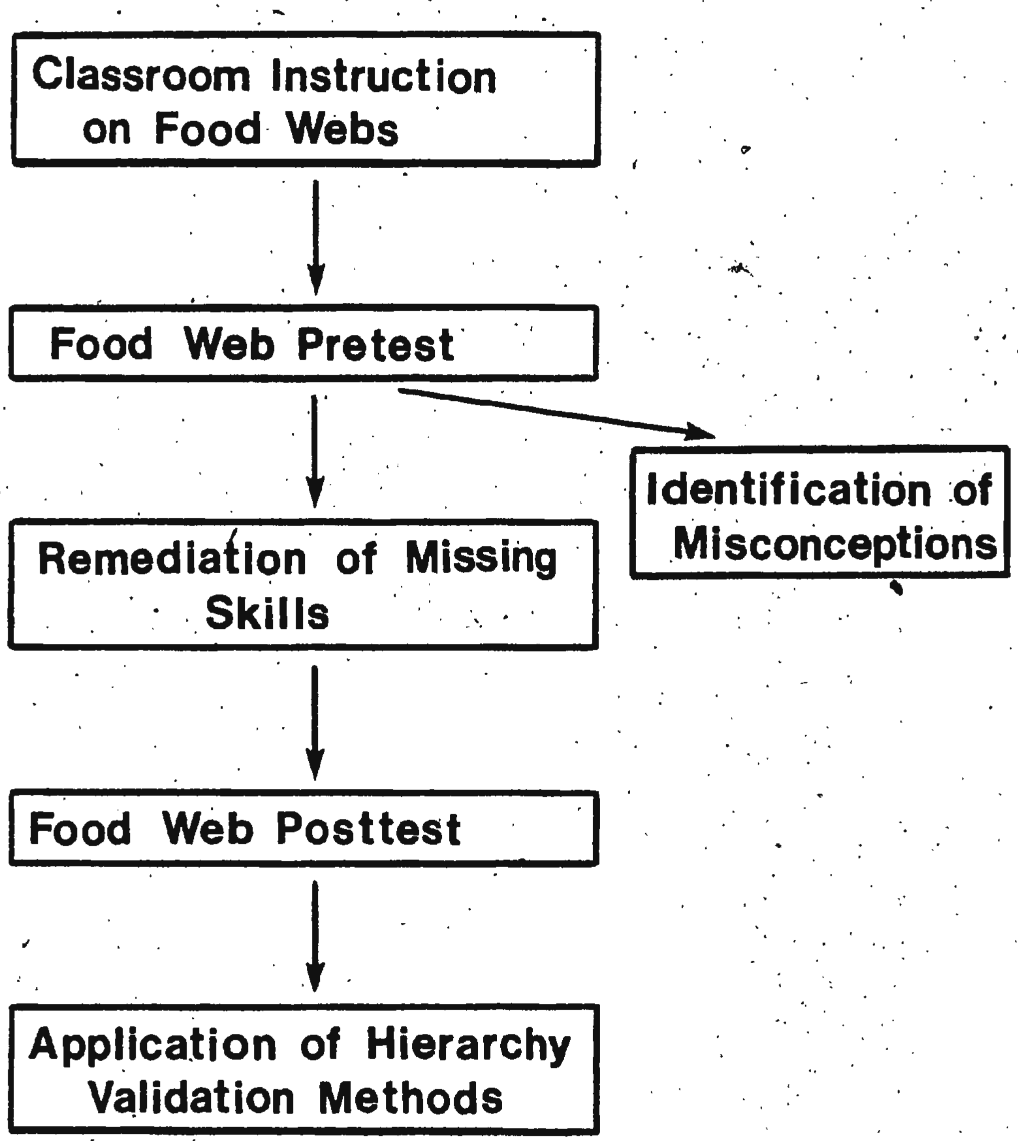


Figure 5. Experimental design of the study.

enable subjects to complete the test within a 40-minute time period, it was necessary to limit the number of items to two per element. As a result, the test consisted of 18 items which were randomly sequenced using a random number table (Glass & Stanley, 1970, p. 510).

Due to the nature of the skills comprising the hierarchy, the factor which tended to differentiate items testing various skills was the relative positioning of the two populations of interest within the food web. As a result, the format of all test items was identical and had the following general arrangement:

In the following food web:

(food web diagram)

If population __ undergoes a sudden
INCREASE (or DECREASE) how will
this affect the size of population __?

Food web diagrams were of moderate complexity, with an average of 11 populations comprising each web. Each population in a food web was represented by a capital letter, and populations were lettered randomly within each web. Subjects were advised of this. Further, in an attempt to remove any confounding influence through the misinterpretation of the arrows between populations in the web, they were reminded that arrows ran from prey populations to predator populations.

The pilot data suggested that the same skill was involved in determining the effect of an increase in size as that of a decrease in size of a given population. Therefore, for each pair of items testing a given skill, one involved an increase in the size of a population while the other involved a decrease. Distractors were not included in the format of the test items, and the names of populations under consideration were underlined, to facilitate interpretation of test items.

Test items were of the "open-ended response" type. Subjects were provided with space on which to write their response and were instructed to provide brief reasons for their responses. This open format provides some measure of whether or not subjects' answers represented guessing on the part of students. Further, it provides a means to identify particular student misconceptions when they exist.

The test instrument was field tested using 37 grade ten biology students who were of similar background to the target population. Revisions in the original test were made to improve language level and clarity of instructions and diagrams.

The posttest was identical in format to the pretest, except for the order in which items testing particular skills appeared.

In order to ensure good content validity before testing, two experienced biology teachers and a science educator rated the congruence between test items and behavioural statements of the related skills and found it appropriate. Tetrachoric correlation coefficients were computed to determine the degree of correlation between test items testing the same skill, for both the pretest and posttest. In order to improve the consistency of measurement of student responses to test items, all tests were marked by one person (the researcher), item by item, and then remarked by the researcher, test by test. The results of both marking procedures were compared for consistency. A second marker corrected 10% of the test papers and these results were compared with those of the first marker for consistency.

The Remedial Booklet

As previously indicated, the remedial booklet was designed for use in the determination of transfer of learning. In order to determine the existence and strength of transfer of learning from subordinate to superordinate skills, subjects were assigned remedial booklets and requested to complete assigned sections.

The remedial booklet consisted of nine units. Each unit corresponded to a particular element in the hypothesized hierarchy. The units were sequenced according to the hypothesized hierarchical order, beginning with the lower skills of the hierarchy and continuing to the terminal skill.

Gagné (1962, p. 357) has identified four main functions to be served by instruction in a learning hierarchy. These include informing the learner of the nature of the performance to be learned; helping the learner to identify appropriate components of the stimulus situation, such as new symbols and terms; establishing high recallability of the elements in the hierarchy; and providing guidance to thinking. In designing the remedial booklet, care was taken to ensure that Gagné's suggestions were heeded in the instruction of each unit.

Each unit began with a statement of the skill to be learned. The instructions which followed attempted to stimulate the recall of relevant subordinate elements and to guide the direction of thinking. In each case, explanations of how the present element related to other elements in the hierarchy were provided, in addition to a diagrammatic representation in the form of a flow chart fashioned after the hypothesized hierarchical arrangement of skills. The remedial units attempted to link the skill to be learned with the subjects' general knowledge by utilizing subject matter and examples which were familiar to the subjects. For example, food webs were often comprised of native Newfoundland species. Occasionally, more exotic examples (prehistoric food web, arctic food web) were used in an effort to catch the learner's interest. At the end of each unit a "Test Yourself" section was presented in which students worked through three sample questions testing the objective of the unit. An answer key was provided for feedback.

Finally, there are many aspects of personal instruction between teachers and their students which serve to motivate, persuade and establish attitudes and values. In an attempt to provide these aspects of teaching to the learning program, the design of the booklet also incorporated pictures, comic characters, encouraging words and humour. This aspect was also important to the experimental design, in that students were instructed to do all remedial work on their own time, as homework. It was hoped that students would be more willing to complete the work if the exercise was not too formal.

The booklet was examined by a science instructor and three biology teachers with respect to its suitability for the test population. Revisions were made to accommodate the suggestions of these experts.

The design, instrumentation and procedures described in this chapter produced the data which were used to test the validity of the hypothesized hierarchy and to identify prevalent student misconceptions. The analysis of these data is discussed in the next chapter.

Chapter 4

RESULTS AND DISCUSSION

Introduction

The data which are used to test the validity of a hypothesized learning hierarchy are derived from responses of a number of individuals to items testing intellectual skills comprising the hierarchy. The validity and reliability of these tests are therefore very important. This chapter begins by considering the validity and reliability of the tests applied in the present study. This is followed by discussions of the application of two psychometric validation procedures, the ordering-theoretic method developed by Bart and others (Bart & Krus, 1973; Airasian & Bart, 1975) and, where appropriate, the Dayton and Macready (1976a) scaling method. Upon consideration of the results of these analyses, a decision regarding the validity of the hypothesized hierarchy is made and a psychometrically validated hierarchy is presented. This hierarchy is further investigated with respect to the degree of transfer of learning which occurs from subordinate to related superordinate skills, using a procedure developed by Griffiths (1979, p. 196). The hierarchy which emerges at this stage represents the validated hierarchy of the present study.

A further aspect of the present study involves the presentation of misconceptions which are held by subjects with regard to the food web concept. Misconceptions which commonly emerged are indicated and discussed.

A computer program developed by Dayton and Macready (1976b) was used in the application of the Dayton and Macready analysis. Other statistical procedures were performed using the SPSS statistical package (Nie, Hull, Jenkins, Steinbrenner & Bent, 1975), unless otherwise indicated.

Validity of the Food Web Skills Tests

The ordering-theoretic and Dayton and Macready methods, as well as the test of transfer used in the present study, require a decision of the mastery status of each individual with respect to each intellectual skill in the hypothesized hierarchy. As a result, the food web pretest and posttest are essentially composed of nine small criterion-referenced tests, one for each skill being tested. Gagné (1969) suggests that the most important consideration in the construction of criterion-referenced tests is that they should have good content validity. To ensure this, two experienced biology teachers and a science educator examined the congruence between each test item and the corresponding behavioural statement of the related skill. All items were considered to be acceptable by all reviewers. The pretest and posttest items were then piloted using two classes of grade ten biology students who were not part of the main study. Analysis of the pilot data indicated the need for some changes in the test instruments. The format of the test items was altered to specify that students indicate the effect of a change in one population on a second population in terms of a size change. The purpose of this change was to discourage students from employing concepts other than predator-prey relationships in their responses, as concepts such as "competition" and "predator switching strategies" were not investigated in the present study. Items testing Skill 6 ("Given a food web diagram, the subject indicates all possible pathways through which the effect of a change in one population is transmitted to a second population") were rewritten because results from the pilot study indicated that subjects misinterpreted the items, or indicated that they did not understand the instructions. This skill proved to be difficult to test in the form of a written test item, however, items were rewritten in an attempt to clarify the task at hand. Another change involved the inclusion, in each item, of a reminder that arrows in the food web diagram ran from prey populations to predator populations. This skill was considered to be verbal information, and not an intellectual skill; hence, it was not considered to be a part of the hierarchy and was therefore provided within the instructions of each test item.

Reliability of the Food Web Skills Tests

In the present study, each pair of items testing a given skill is used primarily to determine the mastery or nonmastery status of subjects for that skill. Because each test of a skill consists of only two items, conventional test reliability statistics are not meaningful. However, it is reasonable to assume that if two items reliably test the same skill, there should be a large positive correlation between students' responses to these items.

Test items were scored dichotomously: acceptable responses were assigned a score of "1", and incorrect responses were assigned a score of "0". The degree of relationship between dichotomously scored variables may be represented by two different correlation coefficients.

One of these, the phi coefficient, is the Pearson product-moment correlation coefficient applied to dichotomous data. The second is the tetrachoric correlation coefficient. The tetrachoric coefficient is the preferred coefficient for dichotomous data when the two variables being compared may logically be assumed to be continuous, with their joint distribution forming a bivariate normal distribution (Walker & Lev, 1953, p. 274; Tate, 1955, p. 259). If these assumptions are valid, use of the phi coefficient as an index of relationship underestimates the relation between the two variables (Glass & Stanley, 1970, p. 165).

The interpretation of the tetrachoric coefficient can only be meaningful to the extent that the underlying measurements conform to the model of a normal bivariate surface. Carroll (1961, p. 362) suggests that even when psychological characteristics are not distributed exactly in conformity to the normal distribution, any distribution in which deviation from central tendency becomes successively rarer as a function of the magnitude of the deviation is, in all probability, a good approximation to the normal distribution. This appears to be true for most of the abilities being measured by test items in this study. In addition, the "1" and "0" scoring categories may be considered a dichotomy of an underlying continuous ability variable where individuals above a certain threshold value on the ability variable pass the item, and those below it fail. This tends to be supported by the data, where subjects' responses indicated varying degrees of correctness and incorrectness. Had items been assigned a different marking scheme, for example, five marks per item rather than one, a range of scores would almost certainly have resulted.

As a result of the preceding considerations, the tetrachoric correlation coefficient was used as an index of the degree of correlation between the two test items measuring a given skill. The value of a tetrachoric coefficient is determined from the results of a matrix indicating the scores for two items testing a given skill. Figure 6 illustrates such a matrix for two items, "X" and "Y". The letters A, B, C and D represent the frequencies of each of four cells comprising the matrix, where each cell indicates a different pattern of scores for the two skills. When the marginal distributions of the two variables are symmetrical, such that the proportion of students mastering one item is similar to the proportion mastering the second, the following equation may be used to determine the value of the tetrachoric coefficient (r_{tet}):

$$r_{tet} \doteq \cos[180^{\circ} / (1 + \sqrt{BC/AD})] \quad (1)$$

where A, B, C and D correspond to the cell frequencies indicated in the matrix shown in Figure 6. If the assumption of symmetry of distribution of scores cannot be met, substantial errors may result by using Equation 1. If the proportion of subjects failing either skill departs greatly from 0.50, an overly high estimate of the tetrachoric coefficient is produced. The distribution of test scores in the present study were asymmetrical. As a result, Jenkins' (1955) modification for skewed data was applied. Tetrachoric correlation coefficients for pairs of pretest and posttest items are shown in Table 1. The significance level reported in this table represents the level at which the null hypothesis of no correlation between the test items can be rejected.

		ITEM X SCORE	
		Fail (0)	Pass (1)
ITEM Y SCORE	Fail (0)	B	D
	Pass (1)	A	C

Figure 6. An item matrix for the determination of a tetrachoric correlation coefficient.
Note: A, B, C and D represent cell frequencies.

Table 1

Tetrachoric Correlation Coefficients (r_{tet}) Between Items Testing Skills of the Hierarchy

	Skill	Corresponding Test Items	Sample Size (n)	r_{tet}	p
Pretest	1	2,13	149	.85	< .05
	2	5,18	161	*	
	3	6,15	135	.62	< .01
	4	10,16	118	.79	<.001
	5	4,7	163	.72	<.001
	6	12,17	78	.87	<.001
	7	1,14	169	*	
	8	9,11	182	*	
	9	3,18	116	*	
Posttest	1	4,11	164	*	
	2	2,17	135	*	
	3	5,18	123	*	
	4	6,10	164	.75	<.001
	5	1,16	143	.89	< .01
	6	7,14	130	.98	<.001
	7	3,12	161	.95	<.001
	8	9,13	157	.95	<.001
	9	8,15	149	.75	<.001

* r_{tet} could not be determined for items for which zero frequencies occurred in at least one cell of the data matrix.

The range of the tetrachoric coefficient is not restricted by disparate marginal totals of the matrix from which it is determined. As a result, the values which the tetrachoric coefficient can attain range from -1 to +1, and the tabled values can be interpreted accordingly. Ideally, any individual should consistently answer both items testing a given skill. However, in practice such perfect agreement is seldom found. The sample size (n) indicated in Table 1 varies as a result of student absences and the classification of responses which were difficult to interpret as missing data.

The tetrachoric correlation coefficient cannot be determined if one or more cells in the skill matrix have a frequency of zero. As a result, tetrachoric coefficients could not be determined from the pretest data for Skills 7, 8 and 9 because none of the sample correctly answered items testing these skills. However, tetrachoric coefficients were determined from the posttest data for parallel items testing these skills and were found to be highly significant. Skills 1 and 3 were mastered by most students on the posttest. As a result, zero frequencies occurred in at least one cell in each of the corresponding matrices. Although tetrachoric coefficients could not be determined for these skills in the posttest, parallel items were found to correlate well in the analysis of pretest data. Both items testing Skill 2 were answered correctly by 97.5% of the pretest sample and 98.5% of the posttest sample, respectively. As a result, tetrachoric coefficients could not be determined for items testing this skill. All other tetrachoric coefficients indicated a high degree of correlation between the two items testing a given skill, as indicated in Table 1.

Application of the Ordering-Theoretic Method

In order to determine whether the arrangement of intellectual skills presented in the hypothesized hierarchy represents a learning hierarchy which is valid psychometrically, hypothesized hierarchical connections were tested initially by the ordering-theoretic method. Ideally, this method should be applied to only the pretest data. There is a possibility that the posttest data could be biased as a result of subjects' prior exposure to the remedial booklet; although this effect would probably be slight. In the present study it was not possible to use only pretest data because all subjects failed the upper three skills of the hierarchy on the pretest (Table 2). This made testing of connections which involved these skills impossible. Hence, it was necessary to utilize posttest data for the analysis of connections among these skills. The number of subjects used to test each hierarchical connection was not constant. Differences in sample size resulted from the need to eliminate subjects with intermediate test scores, who as a result could not be classified as possessing or lacking a given skill, and subjects whose responses were incomplete or difficult to interpret, from the sample in each case. As a result, the sample ranged from a minimum of 67 subjects to a maximum of 147 subjects in the pretest, and from 83 subjects to 135 subjects in the posttest.

As indicated in Chapter 2, the ordering-theoretic method tests relationships between pairs of skills. The percentage of subjects who fail the subordinate skill of a pair, but pass the superordinate skill is identified and designated as exceptions to the hierarchical connection. In the present study, up to 5% exceptions were taken to represent an allowable level, and the test was applied in both the hypothesized

Table 2

Proportion of Sample Mastering Skills of the Hierarchy

	Skill	Sample Size (n)	Proportion of Sample Mastering this Skill (%)
Pretest	1	149	91.3
	2	161	97.5
	3	135	81.5
	4	118	83.1
	5	163	62.0
	6	78	17.9
	7	169	0.0
	8	182	0.0
	9	116	0.0
Posttest	1	164	99.4
	2	135	98.5
	3	123	91.9
	4	164	84.1
	5	143	91.6
	6	130	74.6
	7	161	56.5
	8	157	54.1
	9	149	18.1

and reverse direction. Table 3 contains the percentage of exceptions for each pair of skills in both directions. For a connection to be considered valid, the percentage of exceptions should be less than 5% for the hypothesized direction, and more than that value in the reverse direction for a given connection. The interpretation of Table 3 may be aided by an illustrative example. Consider the tabled pretest data for Skills 2 and 5. For the connection in which Skill 5 is taken to be superordinate to Skill 2, there are no exceptions (0%) indicated. This means none of the subjects tested exhibited Skill 5 without also exhibiting Skill 2. Thus, a hierarchical relationship is suggested. Consider the reverse connection in which Skill 2 is taken to be superordinate to Skill 5. Table 3 indicates there were 13.3% exceptions to this connection. This means that 13.3% of the subjects tested exhibited Skill 2 but did not exhibit Skill 5. These data offer strong support for the hypothesis that Skill 5 is superordinate to Skill 2, as the number of exceptions was less than the criterion value of 5% in the hypothesized direction, and exceeded that value in the reverse direction.

Before considering the results of the ordering-theoretic analysis, it is important to note the following situations which limit the applicability of this method:

> If few subjects pass both skills in the connection under test, it is not possible to test the connection. (Case A)
>
> If few subjects fail both skills in the connection under test, it is not possible to test the connection. (Case B)

The pretest data of the present study suggest the food web hierarchy may be subdivided, upon consideration of the situations described above. Table 2 indicates that Skills 7, 8 and 9 appear to fall into category A while Skills 1, 2, 3, 4 and, perhaps, 5 fall into category B. Skill 6

Table 3

Ordering-Theoretic Results: Percentage of Exceptions to Hierarchical Connections

		Superordinate Skill								
		1	2	3	4	5	6	7	8	9
Subordinate Skill (Pretest)	1	-		0.0	0.0			0.0	0.0	0.0
	2		-		0.0	0.0		0.0	0.0	0.0
	3	2.1		-				0.0		0.0
	4	4.5	2.1		-			0.0	0.0	0.0
	5		13.3			-			0.0	0.0
	6						-	0.0	0.0	0.0
	7	97.8	98.5	93.8	93.3		20.6	-		0.0
	8	97.8	97.3		93.1	78.8	20.9		-	0.0
	9	97.8	98.9	94.9	92.3	75.0	19.0	0.0	0.0	-
Subordinate Skill (Posttest)	1	-		0.0	0.0			0.0	0.0	0.0
	2		-		0.0	0.0		0.0	0.0	0.0
	3	2.7		-				0.0		0.0
	4	3.7	1.8		-			0.0	0.0	0.0
	5		3.3			-			0.0	0.0
	6						-	0.9	0.9	0.0
	7	32.1	35.7	25.3	27.7		12.0	-		0.0
	8	34.9	35.4		28.8	22.6	11.1		-	0.0
	9	74.8	74.2	63.9	65.7	68.0	43.5	28.0	25.8	-

appears to be moderately difficult. It is not difficult to test the validity of a hypothesized connection between any skill in the A category and any skill in the B category; however it is not possible to test connections between skills within the A category. Similarly, but to a lesser extreme, it is difficult to test connections between skills within the B category. For connections among category A skills (Skills 7, 8 and 9), it is possible to test connections by using posttest data, as substantially more subjects were successful in these skills on the posttest. However, the difficulty in testing connections among category B skills (Skills 1, 2, 3, 4 and 5) becomes magnified in the posttest data, as more subjects became successful in these skills on the posttest. Given this, the pretest data were used to test connections which involved two category B skills, and connections between a category A skill and a category B skill. However, posttest data were used to test connections involving two category B skills. Skill 6 was tested on each set of data.

Consider first the connections between a category A skill and a category B skill, and those between a category A skill and Skill 6. Skill 9 is hypothesized to be superordinate to each of Skills 1, 2, 3, 4, 5 and 6. Skill 7 is hypothesized to be superordinate to each of Skills 1, 2, 3, 4 and 6. Skill 8 is hypothesized to be superordinate to Skills 1, 2, 4, 5 and 6. Table 3 indicates there were no exceptions to any of these hypothesized connections. Conversely, for the reverse relationships in each of these connections, the percentage of exceptions were much larger than would be permitted by even a 5% tolerance level of exceptions in each case. Hence, all connections between each of Skills 7, 8 and 9 and all other skills in the hierarchy were supported.

As indicated in Table 3, the same pattern of results was observed for the posttest data, except that the percentages of exceptions were lower in the case of the reversed connections; however they were still much greater than 5%. For the connections between Skill 7 and Skill 6, and between Skill 8 and Skill 6, respectively, 0.9% of the sample (one subject) exhibited Skill 7 and Skill 8 but not Skill 6. In all cases the hypothesized relationships were supported by the posttest data.

In the posttest, a larger proportion of the sample exhibited mastery of Skills 7, 8 and 9 (Table 2). Hence it was possible to use these data to test connections among these skills. Examination of Table 3 indicates Skill 9 was superordinate to each of Skills 7 and 8, with no exceptions. Conversely, 28.0% of the sample exhibited Skill 7 but not Skill 9, and 25.8% of the sample exhibited Skill 8 but not Skill 9. These data support the hypothesis that Skill 9 is superordinate to each of Skills 7 and 8.

Considering the category B skills, Table 2 indicates that very few subjects failed to exhibit Skill 1 (91.3% mastery), Skill 2 (97.5% mastery), Skill 3 (81.5% mastery) and Skill 4 (83.1% mastery) in the pretest. Skill 5 was slightly more difficult (62.0% mastery). Mastery of these skills was even greater in the posttest (Table 2). Because few subjects failed any of these skills, hypothesized connections between Skills 1 and 3, Skills 1 and 4, Skills 2 and 4, and Skills 2 and 5 are difficult to test. This problem is less serious for the connection involving Skill 5, as this skill appeared to be more difficult than the others. In this case there were no exceptions to the hypothesized connection, and 13.3% exceptions to the reverse connection between the skills. Although it is expected if a learning hierarchy is to be useful for instruction, that a large proportion of the sample will achieve the earliest skills, the high degree of mastery of these skills causes problems in the interpretation of results in terms of a preset criterion level. Clearly, the criterion percentage of exceptions to a connection cannot be greater than the percentage of subjects failing to show mastery of the subordinate skill of a pair under test. When the percentage mastery of both skills in a given connection is unusually high, the number of exceptions will be limited, as few subjects fail to master one of the skills in the connection. Therefore, typical levels of allowed exceptions are no longer meaningful. This appeared to be the case for connections involving Skills 1, 2, 3 and 4. Some measure of the validity of these connections is suggested, however, when one considers that of the small proportion of the sample who did not master both skills, there were no exceptions to the hypothesized connections, while there were 2.1%, 4.5%, 2.1% and 13.3% exceptions, respectively, to reverse connections between Skills 1 and 3, Skills 1 and 4, Skills 2 and 4, and Skills 2 and 5. It appears that the direction of the difference in exceptions observed for the hypothesized and reversed connections tends to support the hypothesized connections. However, this interpretation should be treated with some caution. Some support for the hypothesized connections is also suggested from a consideration of the relative difficulties of the skills. Table 2 indicates that in the pretest, 91.3% of the sample exhibited mastery of Skill 1, while only 81.5% exhibited master of Skill 3, and 83.1% exhibited master of Skill 4, respectively. Likewise, 97.5% of the sample exhibited mastery of Skill 2, compared to 83.1% and 62.0%, respectively, for Skills 4 and 5. The apparent differences in the relative difficulty levels of these skills are also in the direction of the hypothesized relationships among them.

In principle it would be possible to test connections between these lower skills directly, as suggested by White and Gagné (1974). Briefly, they suggest that the validity of a hypothesized connection can be tested by using two groups of learners. One group is taught the hypothesized lower skill of the pair, and then the upper. The second group is taught only the upper skill. The hypothesized connection is then considered valid if more of the first group acquire the superordinate skill than those of the second group. Unfortunately, one limitation of this procedure which was noted by White and Gagné (1974) appears to apply to this situation. Because of the nature of the skills involved, teaching the upper skills (Skills 3, 4 and 5) would necessarily involve instruction in the lower skills (Skills 1 and 2). In addition, because the lower skills deal with predator-prey relationships which most grade ten biology students may have been exposed to through day-to-day experiences, it would be difficult to assume that in teaching one group of students only the upper skill of a hypothesized connection that they would have no knowledge of the lower skill.

It may be possible that a study involving subjects much younger than those used in the present study would permit the possibility of more exceptions and thereby indicate stronger support for the hypothesized connections involving lower skills. Unfortunately, there was no opportunity to pursue this possibility in the present study.

All connections in the hypothesized hierarchy (Figure 4, Chapter 3) were found to represent strong connections in terms of the ordering-theoretic analysis. Application of this method suggests that the data are consistent with the hypothesized hierarchy, although as a result of the high degree of mastery of the lower skills, connections among these skills remain tentative. In the next section, the Dayton and Macready method is applied to determine the goodness of fit of the hypothesized hierarchy to the data.

Application of the Dayton and Macready Method

The Dayton and Macready method is described in detail in Chapter 2. In this procedure, goodness of fit between the data and the hypothesized hierarchy is determined through both a chi-square analysis and the determination of a likelihood ratio expressed as a chi-square. In computing the value of the likelihood ratio, the Dayton and Macready method yields estimates of the misclassification parameters needed to provide a fit between the data and the hypothesized hierarchy. As these values increase, confidence in the hierarchy decreases.

It is very important that subjects are properly classified as masters or nonmasters of each skill comprising the hierarchy, before applying the Dayton and Macready analysis. For this reason, subjects who received an intermediate score of "1", and who therefore could not be clearly classified as possessing or lacking a given skill, were omitted from the analysis.

The results of the ordering-theoretic analysis indicated there were no exceptions to connections between category B skills and category A skills. Hence, all pattern vectors which are inconsistent with the hypothesized hierarchy would have a frequency of zero. Similarly, there were no exceptions to connections among skills in category B, and to connections between Skills 8 and 9, Skills 7 and 9, and Skills 6 and 9 of the category A skills. The most stringent test of the hypothesized hierarchy would therefore exclude these connections, as they would preclude any inconsistent pattern vectors. As a result, the Dayton and Macready analysis was applied to the posttest data for Skills 6, 7 and 8 only, as these were the only connections in which some exceptions were observed.

The null hypothesis under test is that there is no significant difference between the observed frequency of response patterns and those acceptable under the assumption that the hierarchy is valid. Large values of the maximum likelihood estimate and the misclassification parameters indicate criteria for the rejection of the hierarchy under test. Likewise, a significance level of less than 0.05 for the maximum likelihood estimate would indicate a lack of sufficient correspondence between the hierarchy under test and the data.

The results of the Dayton and Macready analysis indicated the hypothesized connections between Skills 6 and 7, and Skills 6 and 8 were consistent with the data, with a maximum likelihood estimate of 0.94 and a significance level greater than 0.80. Like the maximum likelihood estimate, the values of the misclassification parameters were also small (guessing parameter estimate = 0.00; forgetting parameter estimate = 0.02).

The results of the Dayton and Macready analysis support the hypothesized hierarchy. Hence, the hierarchy indicated in Figure 4 (Chapter 3) is considered psychometrically valid. In the section which follows, the transfer aspect of the food web hierarchy will be addressed.

Transfer of Learning Within the Food Web Hierarchy

Research question 2 is concerned with the existence of transfer of learning from subordinate to related superordinate skills in the food web hierarchy. As indicated in Chapter 2, Gagné's index of proportion positive transfer and other indices related to it are not considered to be acceptable tests of the degree of transfer between skills in a hierarchy. In order to investigate the existence of positive transfer in the present study a procedure developed by Griffiths (1979, p. 196) was applied. This procedure was described in Chapter 3. Essentially it investigates the relationship between gain of subordinate skills from pretest to posttest and gain of related superordinate skills. Following regular classroom instruction, students are pretested on all skills comprising the hypothesized hierarchy. In order to test for transfer, remedial instruction is provided for each subject in those skills for which they did not respond correctly in the pretest. This is followed by a posttest of all skills. Yate's corrected chi-square test is then used to determine if those subjects who gained prerequisite skills between testing periods are more successful on posttest items testing the superordinate skills than are those subjects who failed to gain the prerequisite skills.

In order to investigate transfer using this method, a substantial number of subjects must fail to show mastery of the hypothesized skills on the pretest, as these subjects comprise the sample to which the test of transfer is applied. In the case of lower skills of the hierarchy, subjects are less likely to fail to master both skills than in the case of higher skills. In the present study, because a large proportion of the sample mastered most of the lower skills of the hierarchy, the proportion of subjects who failed to exhibit these skills was too small to allow meaningful interpretation of a transfer effect. As a result, connections among Skills 1, 2, 3, 4 and 5 could not be investigated for transfer of learning. The results of the application of the test of transfer for connections among Skills 6, 7, 8 and 9 are presented in Table 4.

Significant transfer of learning was found from Skill 7 to Skill 9 ($p < .001$) and from Skill 8 to Skill 9 ($p < .001$). This implies that learning of Skills 7 and 8 should significantly enhance learning of Skill 9. Significant transfer of learning was also indicated from Skill 6 to Skill 7 ($p < .001$) and from Skill 6 to Skill 8 ($p < .001$), which suggests the learning of Skill 6 should significantly enhance the learning of both Skill 7 and Skill 8.

In the present study, research question 2 could only be answered for the hypothesized connections among Skills 6, 7, 8 and 9. These results were consistent with the hypothesized hierarchy. As a result, the hierarchy which emerges upon completion of both psychometric and transfer validation procedures includes relationships between skills that have been psychometrically validated, as well as several which have been validated both psychometrically and with respect to a transfer criterion. This hierarchy is presented in Figure 7.

In the remainder of this chapter, a discussion of common misconceptions which were identified for the food web concept will be presented.

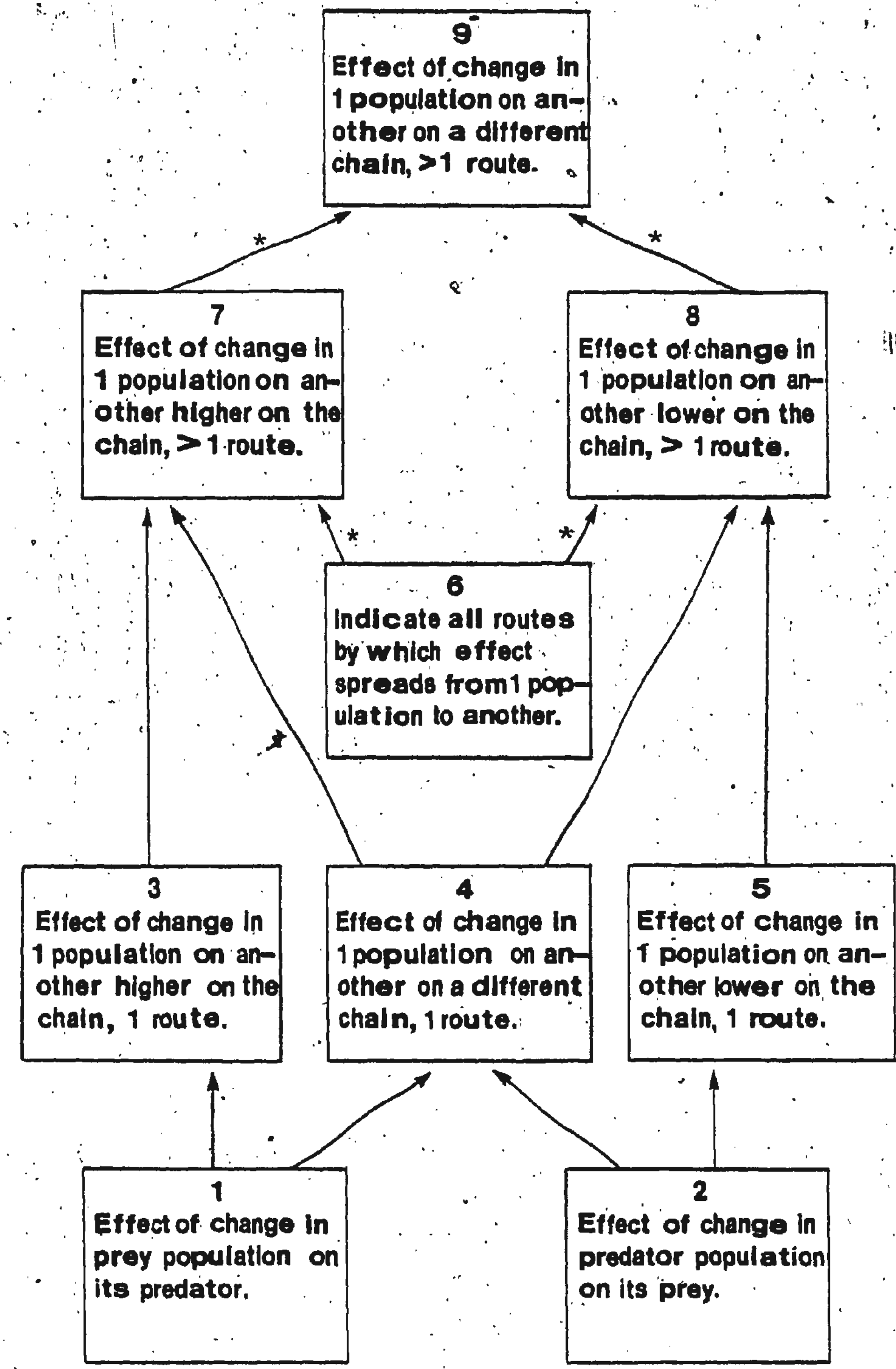


Figure 7. The validated food web hierarchy. Note * indicates those connections which are valid both psychometrically and with respect to transfer. All other connections are psychometrically valid.

Table 4

χ^2 Values for the Transfer of Learning Test

Connection	Subordinate Not Gained		Subordinate Gained		χ^2	p
	Superordinate Failed (n)	Superordinate Passed (n)	Superordinate Failed (n)	Superordinate Passed (n)		
6 → 7	10	0	2	18	18.91	$< .001$
6 → 8	10	0	2	18	18.91	$< .001$
7 → 9	26	0	15	15	15.30	$< .001$
8 → 9	24	0	14	16	15.72	$< .001$

Note: All subsamples (n) are taken from those subjects failing both skills of a particular connection in the pretest.

Analysis of Misconceptions Related to the Food Web Concept

As indicated in Chapter 2, currently there is much interest in the study and identification of students' misconceptions of science concepts. Because the learning hierarchy model lends itself readily to an analysis of misconceptions, an important aspect of the present study involves the identification of students' misconceptions concerning skills comprising the food web hierarchy. Although misconceptions involving skills related to the food web concept were identified in the present study, it should be noted that the remedial booklet was not designed to deal specifically with these misconceptions. The design of the study required that subjects be given the remedial booklet within two days of the pretest. As a result, it was necessary to prepare the remedial booklet well in advance of the analysis of subjects' misconceptions.

Test items used in the present study followed a free-response format. Upon responding to a given item, subjects were asked to indicate the reasoning used in arriving at their answers. This information proved to be useful in evaluating subjects' mastery status with respect to a given skill. Just as importantly, it was useful in providing information which gave clues to subjects' misconceptions. In some cases, it was possible only to make inferences regarding a possible underlying misconception, upon considering the errors made by subjects; in other cases, subjects stated misconceptions openly.

In order to identify misconceptions, all items which were answered incorrectly on the pretest were scrutinized. Taken one item at a time, subjects' explanations of the rationale used in answering these items were analyzed for key ideas or common criteria, and were then transcribed on file cards. A series of categories of misconceptions were developed and coded numerically. In this way, the frequency of each particular misconception could be determined for each skill and for groups of skills. It should be noted that categories of misconceptions were developed after the major common ideas had been identified in subjects' explanations; they were not predetermined categories of misconceptions. Where a subject exhibited more than one misconception in responding to a given item, each individual misconception was reported.

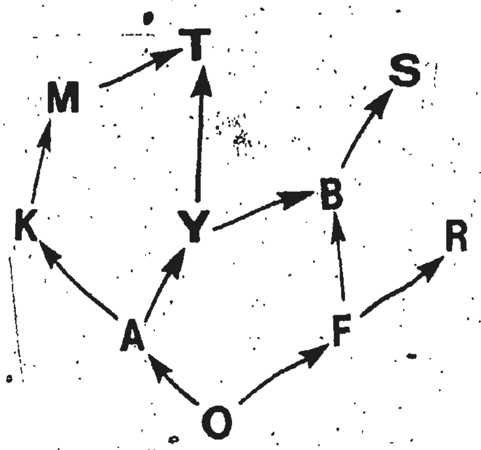
A presentation of misconceptions relating to the food web concept which were most commonly held by subjects in the present study now follows.

Misconception 1: The interpretation of food web dynamics in terms of a food chain.

Almost the entire sample (95.5%) made a common error when asked to determine the effect of a sudden size change in one population on a second population which is part of the same food web. These subjects failed to consider that the effects of a change in one population could be passed along several different pathways as it approached the population in question. Rather, they tended to select one of several pathways and considered successive predator-prey relationships until they reached the population in question. Examples of subjects' responses of this type are presented in Table 5. These students appear to have dealt with food web relationships by applying a strategy better suited to food chains. In a food chain, effects of a size change in one population travel to a second population from one direction, along one pathway of predator-prey relationships. In contrast, the nature of the food web model permits the effects of a change in one population to spread through a "web" of pathways, prior to reaching a population in another

Table 5

Examples of Responses Incorporating Misconception 1

Item	Subjects' Responses
In the following food web:  If population S undergoes a sudden DECREASE in size, how will this affect the size of population K?	"K would undergo an increase, B increases, F decreases, and A increases because there is plenty of O and therefore K increases also." "K would decrease. Because if S decreased B would increase and Y would decrease and T would decrease and M would increase and thus K would decrease." "K will increase because it would cause B to increase and Y to decrease causing A to increase which leaves K with an increase in prey."

part of the web. Each pathway transmits an effect on the population in question, and each should be considered in determining the net effect of the initial change. Unfortunately when subjects were asked to disclose their strategy, they indicated that they utilized one pathway in the web, without explaining why they chose a particular pathway, or why they based their answer upon consideration of only one pathway. Although the underlying misconception was not revealed directly, a possible explanation for this incorrect strategy can be inferred from student responses.

Typically, students encounter the food chain model prior to the food web model. This is quite reasonable, considering that the former represents a less complex model on which students may begin their understanding of feeding relations between different populations in a community. Food webs are often introduced as a more realistic model for the representation of feeding relationships than the simple food chain model. Structurally food webs resemble, and may be described as, a network of food chains. However, misconceptions may occur if students consider a food web to be functionally like a network of individual food chains. Subjects in the present study did not appear to perceive the dynamics of fodd web relationships in terms of an interrelated network of populations. Rather, they persisted in apparently arbitrarily singling out an individual food chain or single pathway of populations in the food web structure and considering only those populations along this chain. The influence of the food chain strategy is apparent, for example, in the following subjects' responses to food web problems presented in the pretest:

> If population K undergoes a sudden increase, it will not affect population G because both are on different food paths (in response to pretest item 3).

> The effect varies because of different routes a food chain could take (in response to pretest item 18).

Brumby (1982) encountered a similar problem in a study involving 52 first-year biology students at a British university. She found that over one-half of the sample interpreted statements involving the food web concept in terms of a food chain. Although Brumby does not address the question of why students tend to interpret the notion of a food web in terms of a food chain, she does note that this problem persisted despite years of secondary school biology.

In the present study, this misconception was encountered for items representing all skills in which effects spread from one population to another along more than one pathway (Skills 6, 7, 8 and 9).

Misconception 2: In a food web, a change in one population will only affect another population if the two populations are directly related as predator and prey.

Surprisingly, following classroom instruction on the food web model, 16% of the sample proposed that if one population in a food web undergoes a sudden size change it will have no effect on a second population which is not directly related as its predator or prey. Examples of responses which indicate this misconception are presented in Table 6. The occurrence of this misconception is especially surprising as it indicated that a considerable proportion of the sample did not appear to understand a basic premise underlying the food web concept: that populations which are not directly related as predator and prey can still influence each other because they are part of a common food web. This misconception was identified for all skills in

Table 6

Examples of Responses Incorporating Misconception 2

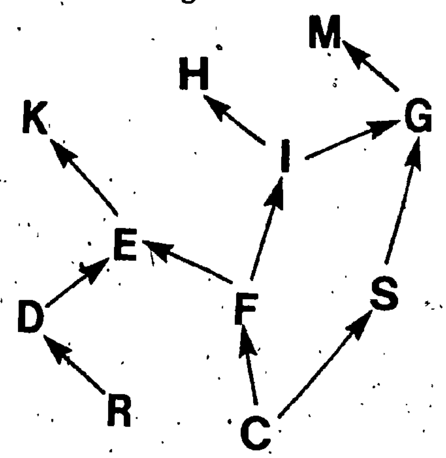
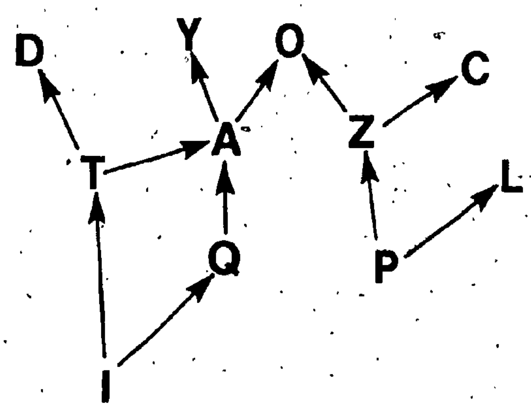
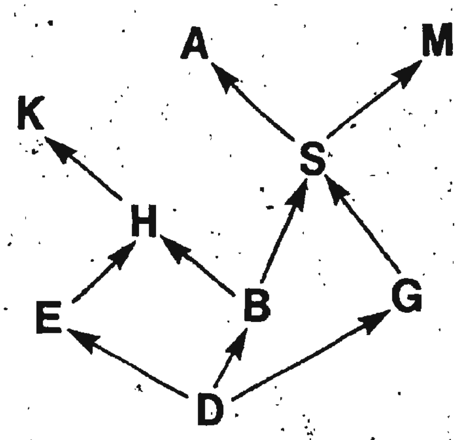
Item	Subjects' Responses
In the following food web:  If population R undergoes a sudden DECREASE in size, how will this affect the size of population E?	"R won't have any effect on E because R is not directly consumed by E."
In the following food web:  If population O undergoes a sudden DECREASE in size, how will this affect the size of population Y?	"No effect. Y doesn't feed on O and vice versa." "There would be no effect. There is no relationship between the two."

Table 6 (Continued)

Item	Subjects' Responses
In the following food web:  If population K ungergoes a sudden INCREASE in size, how will this affect the size of population G?	"It will not affect G. K is not directly connected in a predator-prey relationship." "There would be no effect. There is no relationship between the two." "No effect. The populations are not related in the food web."

which subjects were asked to determine the effect of a change in one population on a second, nonadjacent population (Skills 3, 4, 5, 7, 8 and 9).

A small group of subjects (2.5% of the sample) exhibited a related misconception. When asked to determine the effect of a change in one population on a second population in another part of the web, they suggested the two populations were 'too far apart' to affect each other. These subjects appear to have set an arbitrary distance with regard to how far removed two populations may be, and still affect each other. This misconception occurred in response to Skill 9 only. The populations referred to in items testing Skill 9 tended to be placed on opposite sides of the food web, whereas in other items, the populations under consideration were not so far removed in the web. The following responses are indicative of this misconception:

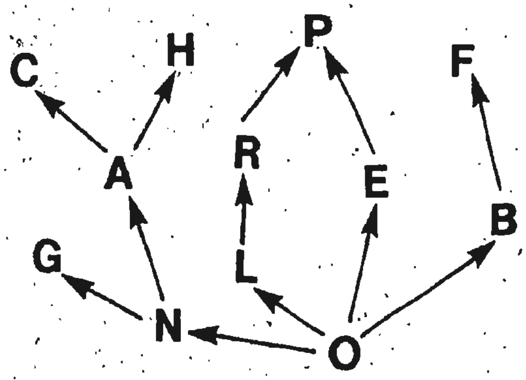
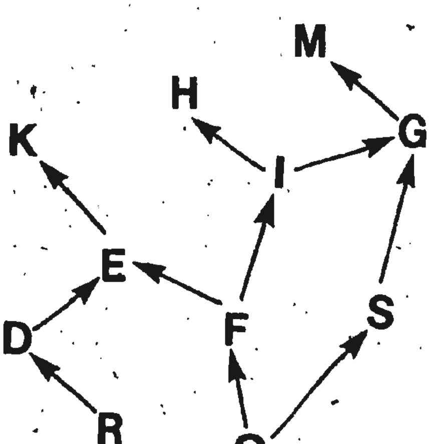
> There will be no effect. The two populations are not really closely linked (in response to pretest item 3).
>
> No effect. The populations are too far away on the food chain (in response to pretest item 18).

Misconception 3: A population located higher on a given food chain within a food web is a predator of all populations located below it in the chain.

Almost one-fifth of the sample (17.5%) incorrectly assumed that a population located higher in a given food chain within a food web is a predator of any population located lower in the chain. As a result, these subjects were prevented from correctly solving problems involving populations which were not directly related as predator and prey. Examples of responses which demonstrate this misconception are presented in Table 7. This misconception was observed in response to items testing skills which require that subjects determine the effect of a change

Table 7

Examples of Responses Incorporating Misconception 3

Item	Subjects' Responses
In the following food web:  If <u>population F</u> undergoes a sudden INCREASE in size, how will this affect the size of <u>population O</u>?	"O will decrease because O isn't changing but more F is preying on O, lessening the population of the not-also-expanding population O." "Population O will decrease because if F increases, that means that there are more predators to eat O, so O will decrease." "Population O will decrease. O is prey and F is predator, therefore O will decrease if there are more F."
In the following food web:  If <u>population R</u> undergoes a sudden DECREASE in size, how will this <u>affect</u> the size of <u>population E</u>?	"E will decrease. If R (the prey) decreases, it will make E (the predator) decrease." "R is being eaten by E. R is prey and E lives off D and R. So it will be no R, so E will decrease."

in one population on a second, nonadjacent population in the food web (Skills 5, 7, 8 and 9).

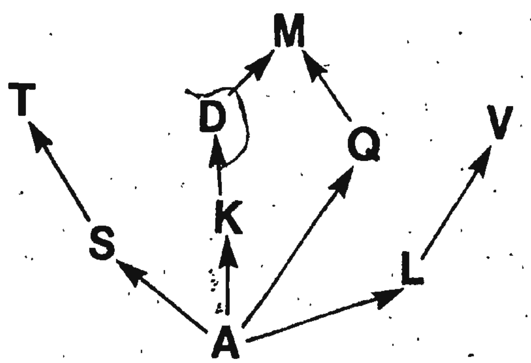
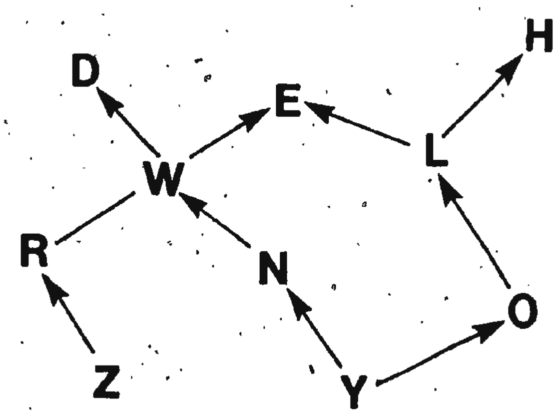
Misconception 4: A change in the size of a prey population has no effect on its predator population.

Six percent of the sample mistakenly believed that a change in the size of a prey population would have no effect on its predator population. Table 8 presents several responses which were based upon this misconception. These subjects appear to be unaware that food supply, in the form of a prey population, is an important factor influencing the size of a predator population. Although this misconception which involves a simple predator-prey relationship did not occur frequently, that such a misconception is found at all at this level of study is a cause for concern. In a study of the predation concept involving elementary students, Powell and Powell (1982) advise that a realistic understanding of this concept is important. They suggest that children who learn to understand predation will have a broader perspective upon which to base important societal decisions concerning conservation of wildlife and population management. It is therefore disturbing to note the persistence of this misconception at the grade ten level.

Although they were observed for only a very small proportion of the sample, two other misconceptions involving the concept of predation were noted. In light of Powell and Powell's (1982) emphasis on the importance of this concept, it was felt they warrant some mention. In the first case, 1% of the sample interpreted predator-prey relationships in an altruistic nature. When a subject was asked to determine the effect of an increase in a predator population, F, on its prey

Table 8

Examples of Responses Incorporating Misconception 4

Item	Subjects' Responses
In the following food web:  If population K undergoes a sudden INCREASE in size, how will this affect the size of population M?	"It will not affect M. The amount of food has nothing to do with the size of a population."
In the following food web:  If population R undergoes a sudden DECREASE in size, how will this affect the size of population W?	"This would not affect population W. Because the only change it will have is R's larger size and therefore it will have more prey." "Population W will stay the same because by R increasing, W will not need more prey to live on if there is already enough." "If R increases, W will remain the same but be healthier. The reason is that there is more food to eat."

population, M, the following response was given:

> M would not have to consume as much to feed F. If F gets bigger, then there is no need to consume as much.

When asked to determine the effect of a decrease in a predator population, L, on its prey population, M, another subject responded:

> If L gets smaller, then W will not have to consume as much for L.

Brumby (1982) found that 21% of her sample of 52 university-level biology students misconstrued predator-prey relationships in much the same way, suggesting that plant populations exist for the benefit of mankind and higher organisms. This suggests an anthropocentric perception of life, on the part of some students, which has persisted despite the formal study of biology in the classroom.

Secondly, some subjects (2% of the sample) appeared to misconstrue the concept of a predator, proposing that of two populations, the population with the greater number is the predator population. This may result from the association of the concept of a predator with "strength"; and the idea that there is strength in numbers. Examples of subjects' responses which indicate the presence of this misconception are presented below (subjects were asked to determine the effect of an increase in a prey population, R, on its predator population, W):

> W will be greatly affected because W is the predator of R. When one population gets bigger, it has to eliminate the other so this is what's happening here. W will decrease.

> If R increases, R will become the predator when W will become the prey.

Misconception 5: If the size of one population in a food web is altered, all other populations in the web will be altered in the same way.

Four percent of the sample appeared to believe that 'whatever happens to one population in a food web, will happen to all populations' in the web'. The following responses are representative of this misconception:

> Population L will decrease because if one part of the food web decreases, this will cause populations throughout the food web to decrease because there is less food (in response to pretest item 1).
>
> If there is an increase, then all other populations increase throughout the web (in response to pretest item 3).
>
> Population L would decrease in size also because they are each interacted and so if one decreases, everything else will be affected also (in response to pretest item 1).

In utilizing these strategies in determining the effect of a change in one part of a food web on another part of the web, these subjects appear to ignore basic predator-prey relationships. They seem to prefer to adopt a strategy which may result from some misconception of the concept of food web stability, in which all populations interact and react to changes in the web. For some reason, these subjects suggest they all react in the same way.

A summary of the five major misconceptions and the skills in which they were applied is presented in Table 9. Examination of Table 9 indicates that misconceptions 1, 2, 3 and 5 were identified from the responses of some subjects to items testing the terminal skill. Further, these misconceptions ran through responses to items testing a number of skills. Conversely, misconception 4, although identified for a number of skills, was not identified in items testing the terminal skill. These two situations emphasize the usefulness of the hierarchical model as a means to diagnose students' precise learning difficulties. Further, although it was not tested directly in the present study, this model offers the prospect, in combination with the identified misconceptions, as a means to remediate learning difficulties and enhance learning.

Table 9

A Summary of Misconceptions Related to the Food Web Concept

Misconception	Skills in which the Misconception Occurred: 1	2	3	4	5	6	7	8	9
1. The interpretation of food web dynamics in terms of a food chain.						X	X	X	X
2. In a food web, a change in one population will only affect another population if they are directly related as predator and prey.			X	X	X		X	X	X
3. A population located higher on a given food chain within a food web is a predator of all populations located below it in the chain.					X		X	X	X
4. A change in the size of a prey population has no effect on its predator population.	X		X	X			X		
5. If the size of one population in a food web is altered, all other populations in the web will be altered in the same way.				X		X	X	X	X

Summary

This chapter has addressed the research questions which form the basis of the present study. In order to determine whether the arrangement of intellectual skills presented in the hypothesized hierarchy were psychometrically valid, hypothesized connections were first tested using the ordering-theoretic method. All hypothesized connections were found to represent strong connections, suggesting that the data are consistent with the hypothesized hierarchy. Due to the large proportion of the sample which mastered the lower skills, however, connections among these skills remain tentative. In order to apply the most stringent test of the Dayton and Macready analysis to the hypothesized hierarchy, only those connections for which there were observed exceptions to the hypothesized relationship were tested. Application of the Dayton and Macready analysis to connections between Skills 6 and 7, and Skills 6 and 8 indicated further support for the hypothesized hierarchy. Hence, research question 1 was answered positively; the food web hierarchy was found to be psychometrically valid.

In order to answer research question 2, "Do any connections between pairs of intellectual skills comprising the hypothesized hierarchy represent connections which are valid in terms of transfer of learning?", Griffiths' test of transfer was applied to the psychometrically validated hierarchy. In the present study the identification of transfer between related skills was hindered because of the large proportion of the sample which mastered the lower skills of the hierarchy on the pretest. As a result, research question 2 could only be answered for connections among Skills 6, 7, 8 and 9. The results of the transfer analyses for these connections were consistent with the hypothesized hierarchy. As a result, this hierarchy was found to be psychometrically valid, and for connections among the upper skills, valid with respect to its transfer properties, also.

With respect to research question 3, several misconceptions concerning the food web concept were identified and discussed. A large majority of students appeared to interpret food web dynamics in terms of the simpler food chain model. In addition, 16% of the sample suggested that populations which are not directly related as predator and prey do not affect each other, even though they belong to a common food web. A third misconception which was apparent in the responses of more than 17% of the sample suggested that a population located higher on a given chain within a food web is a predator of all populations situated below it in the chain. Other misconceptions included the suggestion that a change in the size of a prey population has no effect on its predator, and that when one population's size is altered, all other populations in the web will be altered in the same way. In one case a misconception was identified in responses to items testing subordinate skills of the hierarchy, but was not evident in responses to items testing the terminal skill, suggesting that the learning hierarchy model may be useful in the identification of underlying misconceptions which would not be apparent from responses to items testing the terminal skill alone.

Chapter 5

SUMMARY, IMPLICATIONS AND RECOMMENDATIONS

Summary of the Study

The main purpose of the present study was to identify a learning hierarchy leading to the learning of the food web concept. Although many teachers acknowledge the food web concept to be an important part of the biology curriculum, it is also a concept which may pose some difficulty to students.

The identification of a food web learning hierarchy was considered from both a psychometric and a transfer point of view, as it was felt that both aspects are of importance in the validation of learning hierarchies. A review of the literature relating to learning hierarchy investigations revealed several weaknesses in early methods of hierarchy validation. More recent methods which have been developed to improve upon these shortcomings were discussed, and three of these were applied in the present study. Hopefully, the application of these methods in the present study will contribute further information regarding their practical application.

A secondary purpose of the present study was to determine particular misconceptions which grade ten biology students hold with respect to skills related to the food web concept. There has been much support in the recent science education literature for research of this type. The identification of common misconceptions related to the food web concept represents an attempt to provide useful information for instructional development relating to this concept.

A learning hierarchy was derived for the food web concept using a Gagné-type task analysis. The hierarchy which emerged, as well as the related test and remedial instruments, were examined by a panel of experts which included a science educator and two biology teachers and were then field tested using a group of 37 grade ten biology students. This process resulted in some modification in the hierarchy structure and its test instruments. When the hierarchy appeared to be complete, a pretest was administered to the experimental sample which consisted of eight grade ten biology classes. Each class was pretested as soon as possible following instruction of the topic of food webs in the regular classroom instruction schedule. Following the pretest, a self-instructional booklet which was designed by the investigator for the remediation of component skills of the food web hierarchy was administered to the sample. Each subject received an individualized prescription for the remediation of skills which were not successfully completed on the pretest. Following the remedial phase, a posttest which was a parallel form of the pretest was administered to the subjects in order to measure any gain of skills which were not successfully completed on the pretest.

The pre- and posttest data were then analyzed using two psychometric tests, the ordering-theoretic method and the Dayton and Macready method. In the present study, analysis of the data by the ordering-theoretic method indicated strong support for all connections in the hypothesized hierarchy. As a result, the most stringent test of the data by the Dayton and Macready analysis involved the application of this method to only those connnections for which exceptions to the hypothesized relationship were indicated. The structure of the hypothesized hierarchy was supported by the Dayton and Macready analysis. As a result of these analyses, the arrangement of skills in the hypothesized hierarchy (Figure 4, Chapter 3) was considered to represent a psychometrically valid hierarchy.

Griffiths' test of transfer was also applied to the data, however the high degree of mastery of the lower skills limited its application to connections between skills at the upper levels of the hierarchy. In each case, these connections were shown to indicate significant transfer of learning along the psychometrically validated connections. The validated hierarchy which emerged from the present study is shown in Figure 7 (Chapter 4).

Finally, it was suggested that the learning hierarchy model lends itself readily to the analysis of subjects' misconceptions. Therefore, an important aspect of the present study involved the identification of subjects' misconceptions concerning skills related to the food web concept. A brief review of current research investigating students' misconceptions was presented in Chapter 2. From these studies there appeared to be much support for the potential usefulness of information concerning students' misconceptions, to teachers and curriculum developers. In the present study, all items which were answered incorrectly on the pretest were carefully scrutinized. Taken one at a time, subjects' explanations of the rationale used in answering these items were analyzed for key ideas and common criteria and were then catalogued. The five major misconceptions concerning the food web concept and related skills which were identified in the present study are presented in Chapter 4.

Implications of the Present Study

A major implication of the present study concerns the potential usefulness of the food web hierarchy as an instructional tool in the instruction of food webs. A number of skills have been identified, each of which represents a necessary prerequisite for an understanding of food webs. Where it was possible to test for transfer, it was also shown that the learning of subordinate skills provided substantial positive transfer to the learning of related superordinate skills. This has implications regarding the teaching and design of instructional materials for the concept of a food web.

Secondly, the present study provides some evidence of the application of Gagné's learning hierarchy model to the learning of a concept which involves a substantial proportion of nonmathematical skills. At present there is little evidence in the literature for the applicability of the learning hierarchy model to concepts of this type. The present study suggests that the learning hierarchy model may be quite useful in this application and that further investigation of the application of the learning hierarchy model to subject areas other than mathematics and the physical sciences is warranted.

A third implication of the present study relates to the methodology of learning hierarchy validation. In the present study, the validation of connections involving the lowest skills of the hierarchy presented some difficulty as a result of the large proportion of the sample which mastered these skills. Such a large degree of mastery of lower level skills is not surprising if one considers that for a hierarchy to be useful to instruction, the lowest skills should be readily accessible to the target population. Although a high degree of mastery of both skills in a hierarchical connection does not detract from the validity of the connection, it does cause it to become more difficult to validate empirically. Because the ordering-theoretic method focuses on prespecified tolerance levels for exceptions to hypothesized connections, when both skills in a connection are mastered by most of the sample the analysis is hampered. Exceptions can only occur when one of the skills in a hierarchical connection is not mastered by a significant proportion of the sample. This implies that further research into hierarchy validation techniques should investigate this problem.

Another problem related to high mastery of skills on the part of the sample occurred in the determination of transfer of learning for skills in the hierarchy. A major disadvantage of Griffiths' transfer test became apparent in the present study. The sample which is used to investigate the occurrence of transfer includes only those subjects who are classified as nonmasters for both skills of the connection under test. The size of this sample may be small if at least one of the skills under test has been mastered by most subjects. Within the present study, the size of the sample used in testing several connections involving lower skills was so small that the test of transfer between these skills was not meaningful. Hence, the application of this method appears to require larger numbers of unsuccessful subjects than were available in the present study; however, other available tests of transfer appear to be even less satisfactory. Given the importance of establishing transfer of learning between skills, this presents a problem to learning hierarchy researchers.

A fourth implication of the present study relates to the application of the learning hierarchy model to instructional development, as well as for use in the classroom. Important implications for the design of instructional materials for high school science arise from the present study. Where material to be learned concerns intellectual skills, there is now further support that these skills may be ordered into a hierarchical sequence for efficient learning. Also, in situations where students come to a new course deficient in certain skills, there is support from the present study that learning hierarchies may be used to identify missing skills and to guide the teaching of them. In addition to providing a primary reference for the developer of instructional materials and media, it would appear from the present study that learning hierarchies may be useful to the classroom teacher in the preparation of teacher-presented instruction, the diagnosis of learning problems, and in prescribing the content of remedial instruction.

Finally, the misconceptions which were revealed in the present study have important implications for teachers. It was found that half the experimental sample did not understand feeding relationships between populations as they are represented by a food web. They appeared to interpret food web dynamics in terms of the simpler food chain model. This suggests that although most students are able to distinguish a food chain from a food web in terms of their structure, they may not be able to distinguish these models in terms of the feeding dynamics which they represent. This suggests that teachers should be aware of this problem and should make a conscious effort to prevent or eliminate it. This is even more important upon consideration of the persistence of this misconception to university-level biology (Brumby, 1982).

The five misconceptions identified in the present study have important implications for teachers, as well as to the design of instructional materials related to the learning of food webs, food chains and predation. In addition, the present study suggests that the learning hierarchy model may be useful in the study of students' misconceptions. The identification of a misconception in the present study which was peculiar to subordinate skills but was not evident from responses to the terminal skill alone, suggests that the learning hierarchy model may be valuable in identifying misconceptions which would not be apparent from testing only the terminal skill.

Recommendations for Further Research

Several directions for further research are apparent. These include:

1. Further application of the learning hierarchy model to other science concepts, including those which do not involve substantial amounts of mathematical skills; and further application to concepts from disciplines other than science and mathematics.
2. Extension of hierarchy validation procedures to provide for the testing of hypothesized connections in which a high degree of mastery of skills occurs.
3. Further investigation of the development of more effective methods of testing for transfer between subordinate and superordinate skills in learning hierarchies.
4. Further application of the learning hierarchy model in the investigation of students' misconceptions.

5. Cataloguing of existing validated learning hierarchies for use by educators and instructional developers.
6. Further investigation of the extent of meaningful learning which occurs when students learn according to a learning hierarchy.
7. Further investigation of the application of the learning hierarchy model to studies involving mastery learning.

BIBLIOGRAPHY

Airasian, P.W. & Bart, W.M. Validating a priori instructional hierarchies. Journal of Educational Measurement, 1975, 12(3), 163-173.

Alexander, S.K. Food web analysis: An ecosystem approach. The American Biology Teacher, 1982, 44(3), 186; 189; 190.

Ausubel, D.P. The psychology of meaningful verbal learning. New York: Grune and Stratton, 1963.

______. Educational psychology: A cognitive view. New York: Holt, Rinehart and Winston, 1968.

Ausubel, D.P., Novak, J.D., & Hanesian, H. Educational psychology: A cognitive view (2nd ed.). New York: Holt, Rinehart and Winston, 1978.

Bailey, D.E. An analysis of science misconceptions held by secondary school pupils in North Carolina (Doctoral dissertation, University of North Carolina, 1962). Dissertation Abstracts International, 1962, 23(12), 4567.

Baird, J.R. & White, R.T. A case study of learning styles in biology. European Journal of Science Education, 1982, 4(3), 325-337.

Bart, W.M. & Krus, D.J. An ordering-theoretic method to determine hierarchies among items. Educational and Psychological Measurement, 1973, 33, 291-300.

Beeson, G.W. Hierarchical learning in electrical science. Journal of Research in Science Teaching, 1977, 14(2), 117-127.

______. Influence of knowledge context on the learning of intellectual skills. American Educational Research Journal, 1981, 18(3), 363-379.

Bergan, J.R. The structural analysis of behavior: An alternative to the learning-hierarchy model. Review of Educational Research, 1980, 50(4), 625-646.

Bergan, J.R. & Jeska, P. An examination of prerequisite relations, positive transfer among learning tasks, and variations in instruction for a seriation hierarchy. Contemporary Educational Psychology, 1980, 5(3), 203-215.

Biological Sciences Curriculum Study (BSCS), Biological Science: Patterns and Processes (Teacher's Edition). Toronto: Holt, Rinehart and Winston, 1970.

Bloom, B.S. The 1955 normative study of the tests of general educational development. School Review, 1956, 64, 110-124.

Briggs, L.J. Sequencing of instruction in relation to hierarchies of competence. Pittsburgh, Pennsylvania: American Institute for Research in Behavioral Sciences, 1967. (Report No. AIR G3 10/G7FR)

Brumby, M. Problems in learning the concept of natural selection. Journal of Biological Education, 1979, 13(2), 119-122.

______. Students' perceptions of the concept of life. Science Education, 1982, 66(4), 613-622.

Bruner, J.S. The process of education. Cambridge, Massachusetts: Harvard University Press, 1960.

Capie, W. & Jones, H.L. An assessment of hierarchy validation techniques. Journal of Research in Science Teaching, 1971, 8, 137-147.

Carroll, J.B. The nature of the data, or how to choose a correlation coefficient. Psychometrika, 1961, 26(4), 347-372.

______. Discussion. In L.B. Resnick (Ed.), Hierarchies in children's learning. Instructional Science, 1973, 2, 311-362.

Coletta, J. & Bradley, J. A model for teaching ecology. American Biology Teacher, 1981, 43(6), 320-322; 339.

Cotton, J.W., Gallagher, J.P. & Marshall, S.P. The identification and decomposition of hierarchical tasks. American Educational Research Journal, 1977, 14(3), 189-212.

Dayton, C.M. & Macready, G.B. A probabilistic model for validation of behavioral hierarchies. Psychometrika, 1976a, 41(2), 189-204.

______. Computer programs for probabilistic models. University of Maryland, 1976b.

Deadman, J.A. & Kelly, P.J. What do secondary school boys understand about evolution and heredity before they are taught the topics? Journal of Biological Education, 1978, 12(1), 7-15.

Dewey, J. Democracy and education. New York: Macmillan, 1916.

Dick, W. An alternative analysis of "Formative Evaluation Applied to a Learning Hierarchy" by White and Gagné. Contemporary Educational Psychology, 1980, 5(3), 282-286.

Dick, W. & Carey, L. The systematic design of instruction. Glenview, Illinois: Scott, Foresman, 1978.

Doran, R.L. Misconceptions of selected science concepts held by elementary school students. Journal of Research in Science Teaching, 1972, 9(2), 127-137.

Driver, R. & Easley, J. Pupils and paradigms: A review of literature related to concept development in adolescent science students. Studies in Science Education, 1978, 5, 61-84.

Eisenberg, T.A. & Walbesser, H. Learning hierarchies -- numerical considerations. Journal for Research in Mathematics Education, 1971, 2(4), 244-256.

Erickson, G.L. Children's conceptions of heat and temperature. Science Education, 1979, 63(2), 221-230.

Finley, F.N. & Stewart, J. Representing substantive structures. Science Education, 1982, 66(4), 593-611.

Finley, F.N., Stewart, J., & Yarroch, W.L. Teachers' perceptions of important and difficult science content. Science Education, 1982, 66(4), 531-538.

Gagné, R.M. The acquisition of knowledge. Psychological Review, 1962, 69(4), 355-365.

_______. A psychologist's counsel on curriculum design. Journal of Research in Science Teaching, 1963, 1, 27-33.

_______. The conditions of learning. New York: Holt, Rinehart and Winston, 1965.

_______. Learning hierarchies. Educational Psychologist, 1968, 6(1), 1-9.

_______. The conditions of learning (2nd ed.). New York: Holt, Rinehart and Winston, 1970.

_______. Domains of learning. Interchange, 1972, 3, 1-8.

_______. Learning and instructional sequence. In F. Kerlinger (Ed.), Review of Research in Education (1). Itasca, Illinois: F.E. Peacock, 1973.

_______. Essentials of learning for instruction. Hinsdale, Illinois: The Dryden Press, 1974.

_______. The conditions of learning (3rd ed.). New York: Holt, Rinehart and Winston, 1977.

Gagné, R.M. & Briggs, L.J. Principles of instructional design. New York: Holt, Rinehart and Winston, 1974.

Gagné, R.M., Mayor, J.R., Garstens, H.L., & Paradise, N.E. Factors in acquiring knowledge of a mathematical task. Psychological Monographs, 1962 (Whole No. 526).

Gagné, R.M., & Paradise, N.E. Abilities and learning sets in knowledge acquisition. Psychological Monographs, 1961, 75(14) (Whole No. 518).

Glass, G.V. & Stanley, J.C. Statistical methods in education and psychology. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1970.

Government of Newfoundland and Labrador. High school biology curriculum guide, 1979.

Griffiths, A.K. The mole concept: Investigation of an hierarchical model. Unpublished Doctoral dissertation, University of Alberta, 1979.

———. The problem of establishing transfer between hierarchically related skills. Personal communication, June, 1983.

Griffiths, A.K. & Cornish, A.G. An analysis of three recent methods for the identification and validation of learning hierarchies. A paper presented at AERA, Toronto, 1978. (ERIC Document Reproduction Service No. ED 167 625).

Gunstone, R.F. & White, R.T. Understanding of gravity. Science Education, 1981, 65(3), 291-299.

Guttman, L. A basis for scaling qualitative data. American Sociological Review, 1944, 9, 139-150.

Hancock, C.H. An evaluation of certain popular science misconceptions. Science Education, 1940, 24, 208-213.

Hart, K. A hierarchy of understanding in mathematics. In W.F. Archenhold, R.H. Driver, A. Orton & C. Wood-Robinson (Eds.), Cognitive development research in science and mathematics. Leeds: University of Leeds, 1979.

Hedges, W.D. Testing and evaluation for the secondary school. Belmont, California: Wadsworth, 1966.

Helm, H. Misconceptions of physics amongst South African students. Physics Education, 1980, 15(2), 92-97.

Hopkins, K.D. & Stanley, J.C. Educational and psychological measurement and evaluation. Englewood Cliffs, New Jersey 07632: Prentice-Hall, Inc., 1981.

Jenkins, W.L. An improved method for tetrachoric r. Psychometrika, 1955, 20(3), 253-258.

Johnstone, A.H., Macdonald, J.J. & Webb, G. Misconceptions in school thermodynamics. Physics Education, 1977, 12(4), 248-251.

Johnstone, A.H. & Mahmoud, N.A. Isolating topics of high perceived difficulty in school biology. Journal of Biological Education, 1980a, 14(2), 163-166.

———. Pupils' problems with water potential. Journal of Biological Education, 1980b, 14(4), 325-328.

Johnstone, A.H. & Mughol, A.R. The concept of electrical resistance. Physics Education, 1978, 13(1), 46-49.

Jones, H.L. & Russell, J.M. Hierarchical learning paradigm. Journal of Research in Science Teaching, 1979, 16(6), 489-499.

Kolb, J.R. Effects of relating mathematics to science instruction on the acquisition of quantitative science behaviors. Journal of Research in Science Teaching, 1967, 5, 174-182.

Kuethe, L.J. Science concepts: A study of "sophisticated errors." Science Education, 1963, 47(4), 361-364.

Lebouter- Barrell, L. Concepts of mechanics in young people. Physics Education, 1976, 11(7), 462-466.

Linke, R.D. Replicative studies in hierarchical learning of graphical interpretation skills. British Journal of Educational Psychology, 1975, 45, 39-46.

Merrill, M.D. Correction and review on successive parts in learning a hierarchical task. Journal of Educational Psychology, 1965, 56, 225-234.

Nie, N.H., Hull, C.H., Jenkins, J.G., Steinbrenner, K., & Bent, D.H. Statistical package for the social sciences (2nd ed.). New York: McGraw-Hill, 1975.

Nussbaum, J. Towards the diagnosis by science teachers of pupils' misconceptions: An exercise with student teachers. European Journal of Science Education, 1981, 3(2), 159-169.

Nussbaum, J.& Novak, J.D. An assessment of children's concepts of the earth utilizing structured interviews. Science Education, 1976, 60(4), 535-550.

Odum, E.P. The emergence of ecology as a new integrative discipline. Science, 1977, 195(4284), 1289-1293.

Okey, J.R. A study of formative curriculum evaluation through the use of hierarchical analysis (Doctoral dissertation, Florida State University, 1968). Dissertation Abstracts International, 1969, 30, 1471A.

Okey, J.R., & Gagné, R.M. Revision of a science topic using evidence of performance on subordinate skills. Journal of Research in Science Teaching, 1970, 7(4), 321-325.

Oram, R.F., Hummer, P.J., & Smoot, R.C. Biology: Living systems. Toronto: Charles E. Merrill Publishing Company, 1979.

Owston, R.D. A maximum likelihood approach to the "test of inclusion." Psychometrika, 1979, 44(4), 421-425.

Piaget, J. Cognitive development in children. Journal of Research in Science Teaching, 1964, 2, 170-186.

Posner, G.J. & Strike, K.A. A categorization scheme for principles of sequencing content. Review of Educational Research, 1976, 46(4), 665-690.

Pottle, J.E. A study investigating a hierarchical model relating to to the concept of conservation of mechanical energy. Unpublished M.Ed. thesis, Memorial University of Newfoundland, 1982.

Powell, C.B. & Powell, R.A. The predator-prey concept in elementary education. Wildlife Society Bulletin, 1982, 10(3), 238-244.

Proctor, C.H. A probabilistic formulation and statistical analysis for Guttman scaling. Psychometrika, 1970, 35, 73-78.

Raven, R.J. The development of the concept of momentum in primary school children. Journal of Research in Science Teaching, 1967, 5, 216-223.

Reid, G.A. Learning hierarchies in instructional development: Experiences and directions for research. Paper presented at the annual meeting of the Association for Educational Communication and Technology RTD/DID, Philadelphia, April 1981. (ERIC Document Reproduction Service No. ED 207 510).

Resnick, L.B. Issues in the study of learning hierarchies. In L.B. Resnick (Ed.), Hierarchies in children's learning. Instructional Science, 1973, 2, 311-362.

Resnick, L.B. & Wang, M.C. Approaches to the validation of learning hierarchies. Educational Testing Service, 1969.

Resnick, L.B., Wang, M.C. & Kaplan, J. Task analyses in curriculum design: A hierarchically sequenced introductory mathematics curriculum. Journal of Applied Behavior Analysis, 1973, 6, 679-710.

Schwab, J.J. Problems, topics and issues. In S. Elam (Ed.), Education and the structure of knowledge. Chicago: Rand McNally, 1964(a).

_______. Structure of the disciplines: Meanings and significances. In G.W. Ford & L. Pugno (Eds.), The structure of knowledge and the curriculum. Chicago: Rand McNally, 1964(b).

_______. The teaching of science as enquiry. In J.J. Schwab & P.F. Brandwein, The teaching of science. Cambridge, Massachusetts: Harvard University Press, 1966.

Science - A Process Approach. American Association for the Advancement of Science, Xerox Corporation, 1967.

Simpson, M. & Arnold, B. The inappropriate use of subsumers in biology learning. European Journal of Science Education, 1982, 4(2), 173-182.

Stead, B.E. & Osborne, R.J. Exploring science students' concepts of light. Australian Science Teachers Journal, 1980, 26(3), 84-90.

Stewart, J. Appropriate research in biology education. American Biology Teacher, 1980, 42(8), 484.

______. Difficulties experienced by high school students when learning basic Mendelian genetics. American Biology Teacher, 1982, 44(2), 80-84; 89.

Stewart, J.H. & Atkin, J.A. Information processing psychology: A promising paradigm for research in science teaching. Journal of Research in Science Teaching, 1982, 19(4), 321-332.

Taba, H. Curriculum development; theory and practice. New York: Harcourt Brace Jovanovich, Inc., 1962.

Tate, M.W. Statistics in Education. New York: The Macmillan Company, 1955.

Trembath, R.J. & White, R.T. Mastery achievement of intellectual skills. Journal of Experimental Education, 1979, 47(3), 247-252.

Uprichard, A.E. The effect of sequence in the acquisition of three set relations: An experiment with preschoolers. Arithmetic Teacher, 1970, 17(7), 597-604.

Viennot, L. Spontaneous reasoning in elementary dynamics. European Journal of Science Education, 1979, 1(2), 205-221.

Walbesser, H.H. & Eisenberg, T.A. A review of research on behavioral objectives and learning hierarchies, 1972 (ERIC Document Reproduction Service No. ED 059 900).

Walker, H.M. & Lev. J. Statistical Inference. New York: Holt, Rinehart & Winston, Inc., 1953.

Warren, J.W. Circular motion. Physics Education, 1971, 6(2), 74-78.

______. The mystery of mass-energy. Physics Education, 1976, 11(1), 52-54.

Weaver, A.D. Misconceptions in physics prevalent in science textbook series for elementary schools. School Science and Mathematics, 1965, 65, 231-240.

Wheeler, A.E. & Kass, H. Student misconceptions in chemical equilibrium. Science Education, 1978, 62(2), 223-232.

Whelan, P.J. A study investigating a hierarchical model relating to stoichiometric calculations. Unpublished M.Ed. thesis, Memorial University of Newfoundland, 1982.

White, R.T. Research into learning hierarchies. Review of Educational Research, 1973, 43(3), 361-375.

______. Indexes used in testing the validity of learning hierarchies. Journal of Research in Science Teaching, 1974a, 11(1), 61-66.

______. A model for validation of learning hierarchies. Journal of Research in Science Teaching, 1974b, 11(1), 1-3.

______. The validation of a learning hierarchy. American Educational Research Journal, Spring 1974c, 11(2), 121-136.

White, R.T. & Clark, R.C. A test of inclusion which allows for errors of measurement. Psychometrika, 1973, 38, 77-86.

White, R.T. & Gagné, R.M. Past and future research on learning hierarchies. Educational Psychologist, 1974, 11(1), 19-28.

______. Formative evaluation applied to a learning hierarchy. Contemporary Educational Psychology, 1978, 3, 87-94.

Wiegand, V.K. A study of subordinate skills in science problem solving. In Resnick, L.B. (Ed.), Hierarchies in children's learning. Instructional Science, 1973, 2, 311-362.

Wood, W.A. A significance test for ordering theory (Doctoral dissertation, Boston College, 1974). Dissertation Abstracts International, 1975, 35, 7145A (University Microfilms No. 75-10, 786, 175 pp.).

APPENDIX A

THE FOOD WEB PRETEST

Note: The dimensions of the following reproduction have been reduced to approximately three-quarters of the size of the original.

NAME: ____________________

SCHOOL: ____________________

GRADE: ____________________

DATE: ____________________

INSTRUCTIONS

1. Answer all of the questions in the spaces provided.

2. In some questions you will be required to briefly explain the reasoning you used to get your answer; be sure to clearly state your reasons.

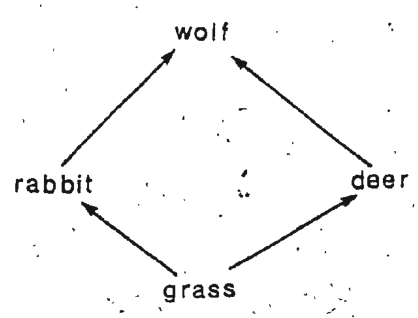
3. If you have difficulty answering a question, proceed to the next one, then come back to the difficult one later.

4. Do any rough work on the food web diagram, if you wish.

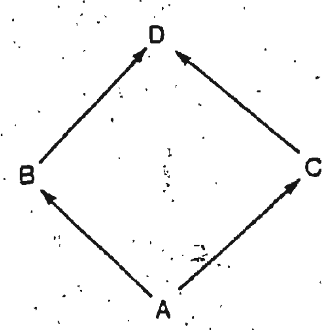
IMPORTANT

This test deals with food webs. The food web diagrams in the test do not contain names of animal populations. CAPITAL LETTERS are used to represent the various populations in a web.

So, instead of:



You will see:



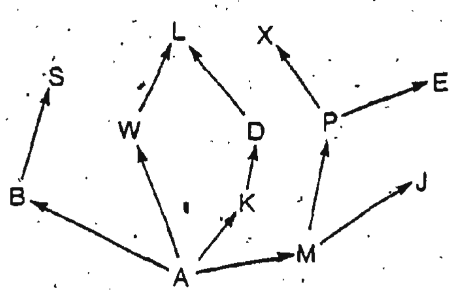
(Note: the letters used are randomly selected, and are not related in any way to specific populations.)

Arrows are always drawn from the prey to the predator.

Example: grass $\longrightarrow$ deer
(prey) (predator)

To remind you how to interpret the arrows, each question will have the following information: (prey $\longrightarrow$ predator).

1. In the following food web: (prey ⟶ predator)



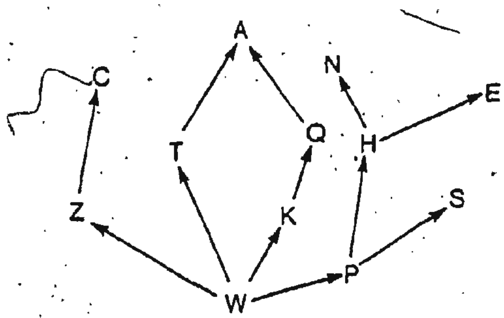
a. If population K undergoes a sudden DECREASE in size, how will this affect the size of population L?

ANSWER: ____________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ____________________

2. In the following food web: (prey ⟶ predator)



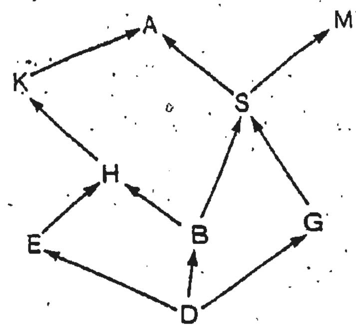
a. If population P undergoes a sudden DECREASE in size, how will this affect the size of population S?

ANSWER: ____________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ____________________

3. In the following food web: (prey ⟶ predator)



a. If population K undergoes a sudden INCREASE in size, how will this affect the size of population G?

ANSWER: ______________________________

____

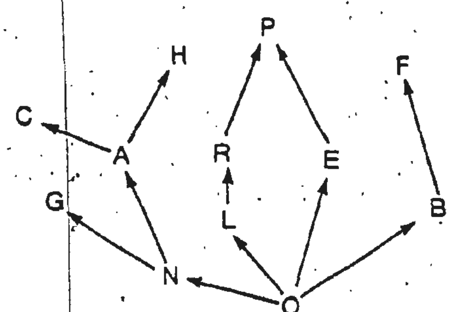
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

4. In the following food web: (prey ⟶ predator)



a. If population F undergoes a sudden INCREASE in size, how will this affect the size of population O?

ANSWER: ______________________________

____

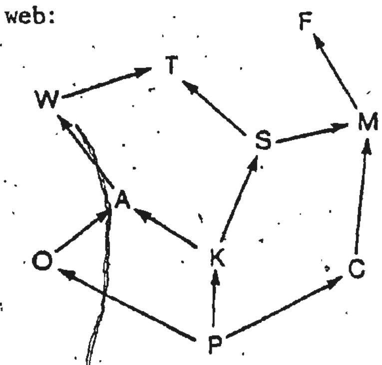
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

5. In the following food web: (prey ⟶ predator)



a. If population F undergoes a sudden INCREASE in size, how will this affect the size of population M?

ANSWER: ______________________________

____

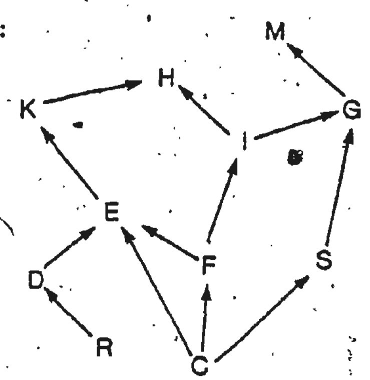
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

6. In the following food web: (prey ⟶ predator)



a. If population R undergoes a sudden DECREASE in size, how will this affect the size of population E?

ANSWER: ______________________________

____

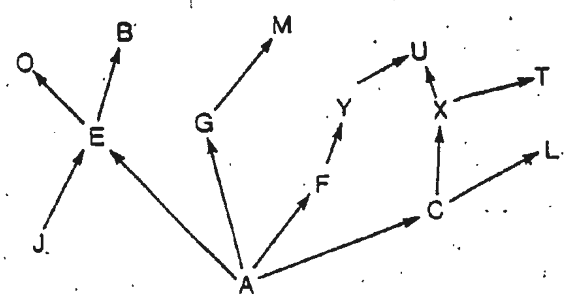
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

7. In the following food web: (prey ⟶ predator)



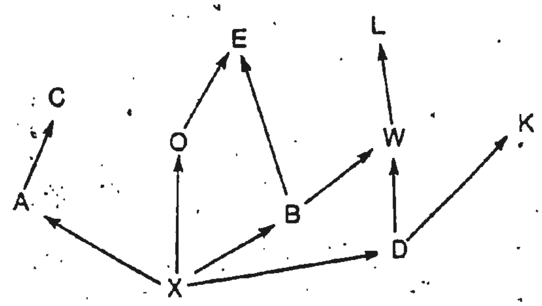
a. If population M undergoes a sudden DECREASE in size, how will this affect the size of population A?

ANSWER: ______________________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

8. In the following food web: (prey ⟶ predator)



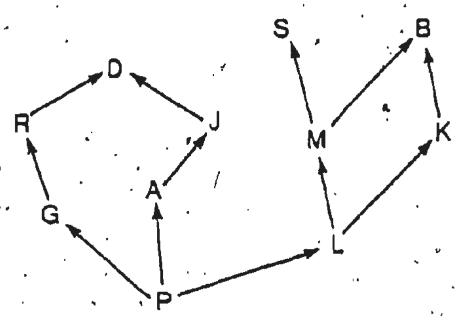
a. If population L undergoes a sudden DECREASE in size, how will this affect the size of population W?

ANSWER: ______________________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

9. In the following food web: (prey ⟶ predator)



a. If population D undergoes a sudden DECREASE in size, how will this affect the size of population G?

ANSWER: ____

____

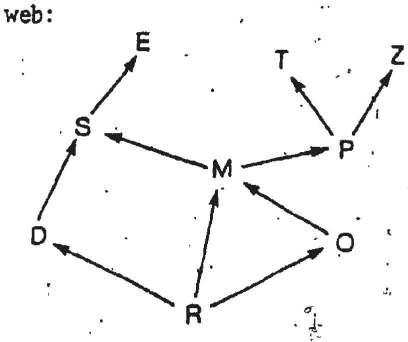
b. In a few words, explain the reasoning behind your answer:

REASONING: ____

____

____

10. In the following food web: (prey ⟶ predator)



a. If population T undergoes a sudden INCREASE in size, how will this affect the size of population Z?

ANSWER: ____

____

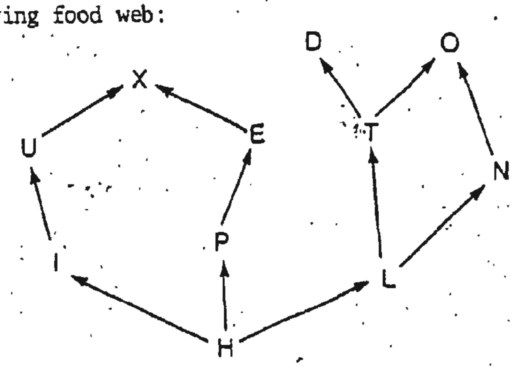
b. In a few words, explain the reasoning behind your answer:

REASONING: ____

____

____

11. In the following food web: (prey → predator)



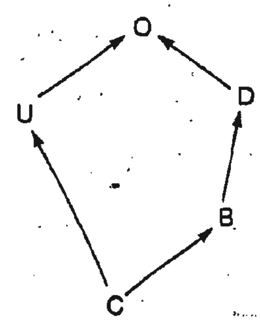
a. If population X undergoes a sudden INCREASE in size, how will this affect the size of population P?

ANSWER: ______________________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

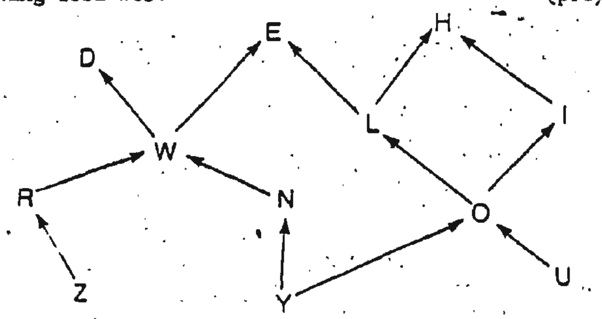
12. a. On the following web diagram, CIRCLE the letters of populations through which the effects of a change in the size of population B would be passed on to population O.



b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

13. In the following food web: (prey⟶predator)



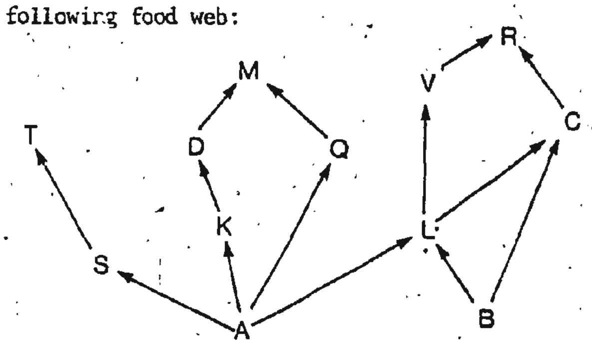
a. If population R undergoes a sudden INCREASE in size, how will this affect the size of population W?

ANSWER: ____________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ____________________

14. In the following food web: (prey⟶predator)



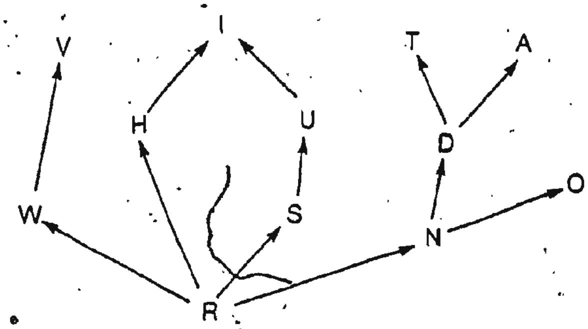
a. If population K undergoes a sudden INCREASE in size, how will this affect the size of population M?

ANSWER: ____________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ____________________

15. In the following food web: (prey ⟶ predator)



a. If population N undergoes a sudden INCREASE in size, how will this affect the size of population A?

ANSWER: ______________________________

____

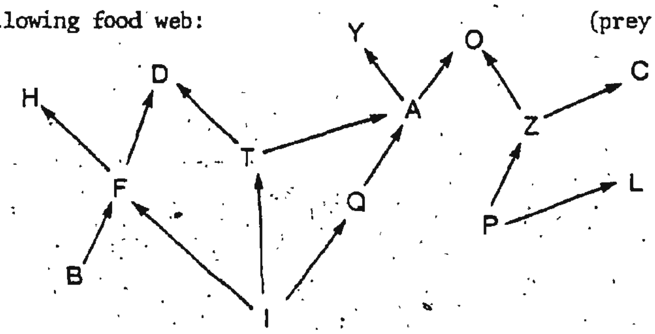
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

16. In the following food web: (prey ⟶ predator)



a. If population O undergoes a sudden DECREASE in size, how will this affect the size of population Y?

ANSWER: ______________________________

____

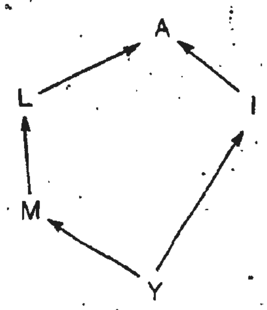
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

17. a. On the following food web diagram, CIRCLE the letters of populations through which the effects of a change in the size of population M would be passed on to population A.



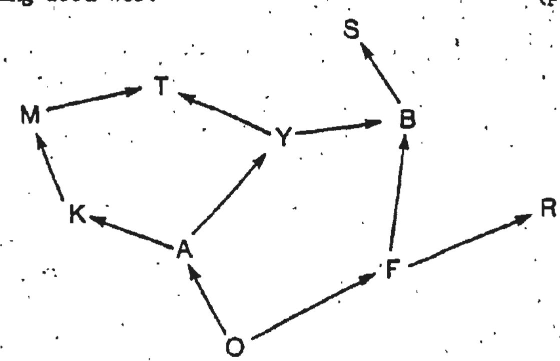
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

18. In the following food web: (prey ⟶ predator)



a. If population S undergoes a sudden DECREASE in size, how will this affect the size of population K?

ANSWER: ______________________________

____

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

APPENDIX B

THE FOOD WEB POSTTEST

Note: The dimensions of the following reproduction have been reduced to approximately three-quarters the size of the original.

NAME: ____________________

SCHOOL: ____________________

GRADE: ____________________

DATE: ____________________

INSTRUCTIONS

1. Answer all of the questions in the spaces provided.

2. In some questions you will be required to briefly explain the reasoning you used to get your answer; be sure to clearly state your reasons.

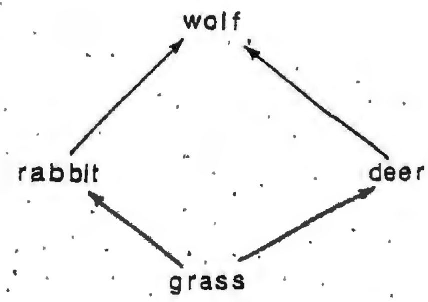
3. If you have difficulty answering a question, proceed to the next one, then come back to the difficult one later.

4. Do any rough work on the food web diagram, if you wish.

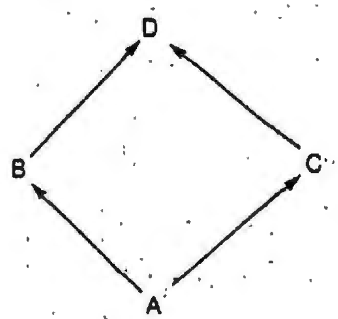
IMPORTANT

This test deals with food webs. The food web diagrams in the test do not contain names of animal populations. CAPITAL LETTERS are used to represent the various populations in a web.

So, instead of:



You will see:



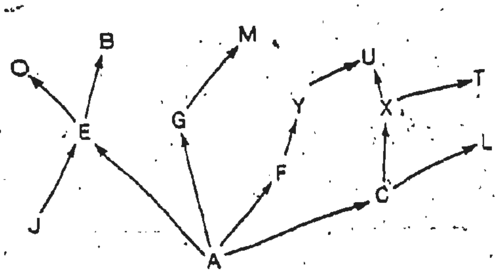
(Note: the letters used are randomly selected, and are not related in any way to specific populations.)

Arrows are always drawn from the prey to the predator.

Example: grass ⟶ deer
(prey) (predator)

To remind you how to interpret the arrows, each question will have the following information: (prey ⟶ predator).

1. In the following food web: (prey ⟶ predator)



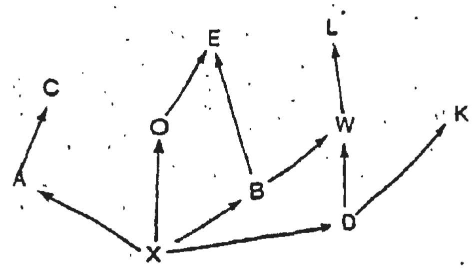
a. If population M undergoes a sudden DECREASE in size, how will this affect the size of population A?

ANSWER: ______________________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

2. In the following food web: (prey ⟶ predator)



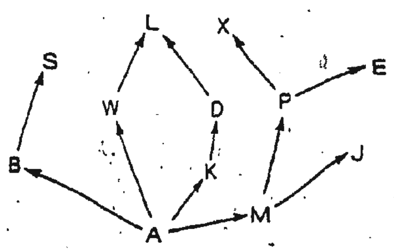
a. If population L undergoes a sudden DECREASE in size, how will this affect the size of population W?

ANSWER: ______________________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

3. In the following food web: (prey → predator)



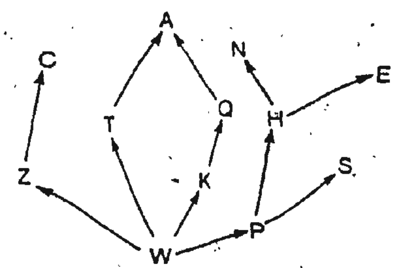
a. If population K undergoes a sudden DECREASE in size, how will this affect the size of population L?

ANSWER: ______________________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

4. In the following food web: (prey → predator)



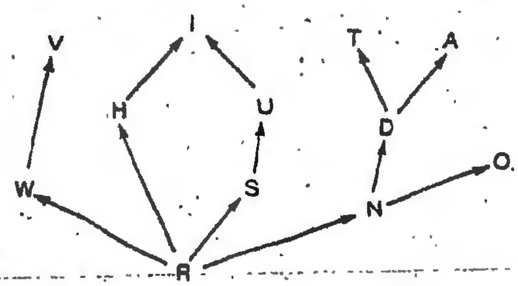
a. If population P undergoes a sudden DECREASE in size, how will this affect the size of population S?

ANSWER: ______________________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

5. In the following food web: (prey ⟶ predator)



a. If population N undergoes a sudden INCREASE in size, how will this affect the size of population A?

ANSWER: ______________________________

____

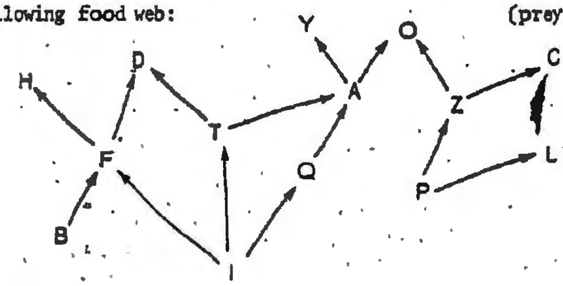
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

6. In the following food web: (prey ⟶ predator)



a. If population O undergoes a sudden DECREASE in size, how will this affect the size of population Y?

ANSWER: ______________________________

____

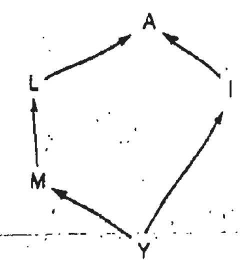
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

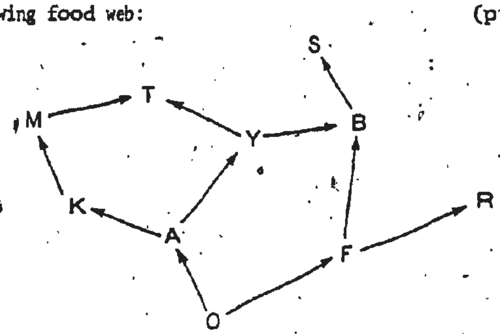
7. a. On the following food web diagram, CIRCLE the letters of populations through which the effects of a change in the size of population M would be passed on to population A.



b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

8. In the following food web: (prey ⟶ predator)



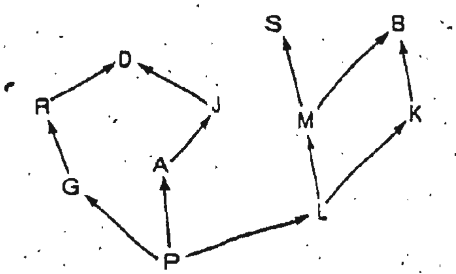
a. If population S undergoes a sudden DECREASE in size, how will this affect the size of population K?

ANSWER: ______________________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

9. In the following food web: (prey ⟶ predator)



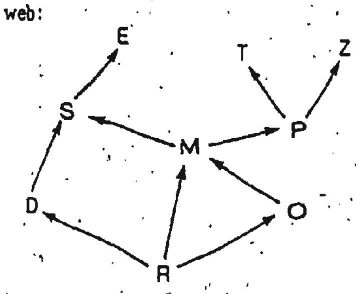
a. If population D undergoes a sudden DECREASE in size, how will this affect the size of population G?

ANSWER: ____________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ____________________

10. In the following food web: (prey ⟶ predator)



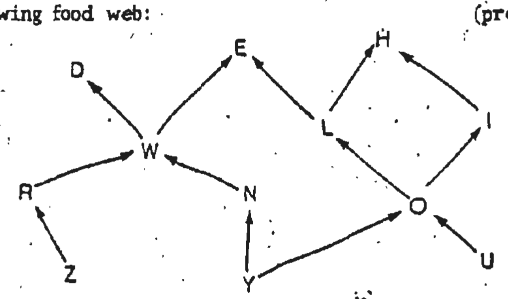
a. If population T undergoes a sudden INCREASE in size, how will this affect the size of population Z?

ANSWER: ____________________

b. In a few words, explain the reasoning behind your answer:

REASONING: ____________________

11. In the following food web: (prey ⟶ predator)



a. If population R undergoes a sudden INCREASE in size, how will this affect the size of population W?

ANSWER: ______________________________

____

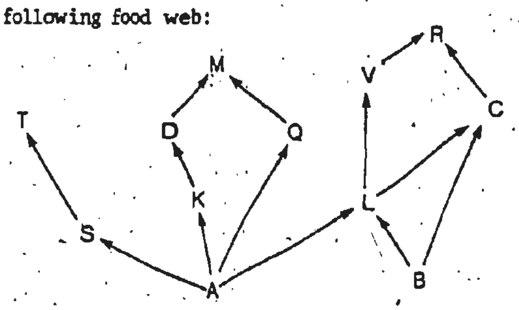
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

12. In the following food web: (prey ⟶ predator)



a. If population K undergoes a sudden INCREASE in size, how will this affect the size of population M?

ANSWER: ______________________________

____

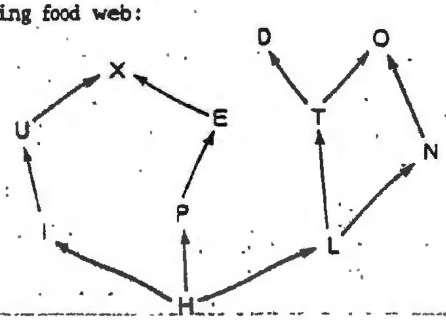
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

13. In the following food web: (prey ⟶ predator)



a. If population X undergoes a sudden INCREASE in size, how will this affect the size of population P?

ANSWER: ____________________

____

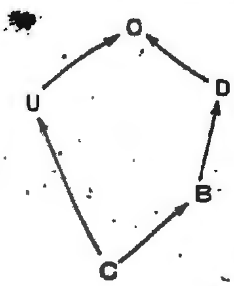
b. In a few words, explain the reasoning behind your answer:

REASONING: ____________________

____

____

14. a. On the following web diagram, CIRCLE the letters of populations through which the effects of a change in the size of population B would be passed on to population O.



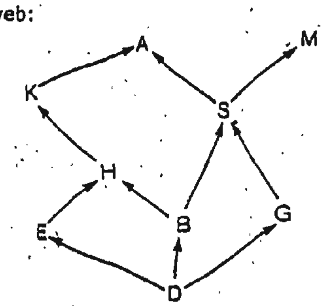
b. In a few words, explain the reasoning behind your answer:

REASONING: ____________________

____

____

15. In the following food web: (prey ⟶ predator)



a. If population K undergoes a sudden INCREASE in size, how will this affect the size of population G?

ANSWER: ______________________________

____

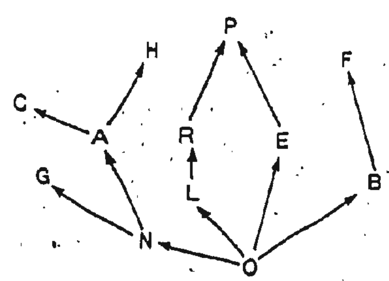
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

16. In the following food web: (prey ⟶ predator)



a. If population F undergoes a sudden INCREASE in size, how will this affect the size of population O?

ANSWER: ______________________________

____

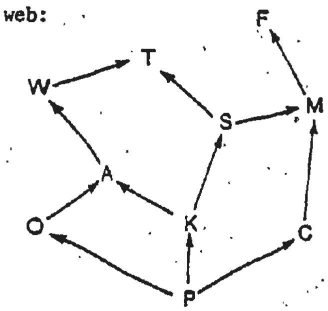
b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

____

17. In the following food web: (prey ⟶ predator)



a. If population F undergoes a sudden INCREASE in size, how will this affect the size of population M?

ANSWER: ______________________________

____

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

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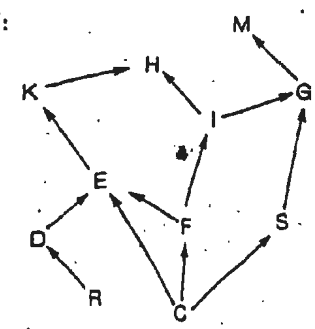
18. In the following food web: (prey ⟶ predator)



a. If population R undergoes a sudden DECREASE in size, how will this affect the size of population E?

ANSWER: ______________________________

____

b. In a few words, explain the reasoning behind your answer:

REASONING: ______________________________

____

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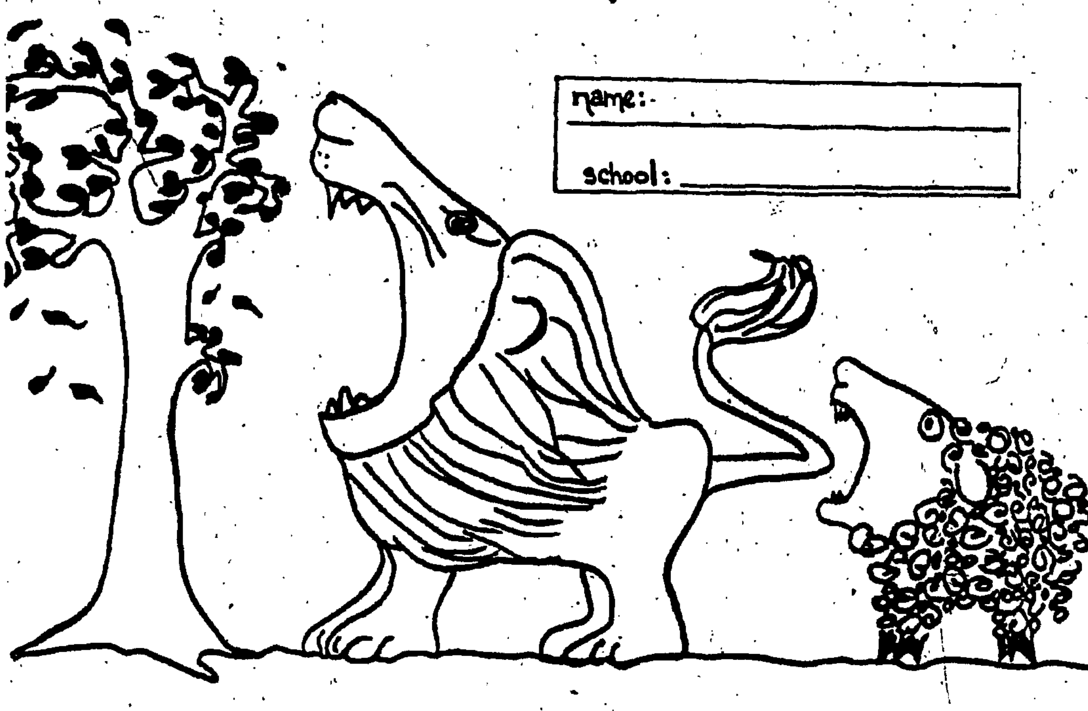
APPENDIX C

THE REMEDIAL BOOKLET

Note: The dimensions of the following reproduction have been reduced to approximately three-quarters the size of the original.

The Ecology of
FOOD WEBS

— a self-instructional booklet



name:- ______________________

school: ______________________

by B. Grant

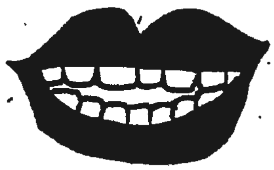
1.

Understanding how various populations interact with each other is an important part of understanding ecology. Recently, you were tested on your knowledge of predator-prey relationships in food webs.

This booklet has been specially designed to provide "another look" at some of the more difficult concepts involved in interpreting predator-prey relationships in food webs.

The concepts which gave you difficulty were indicated in the results of your test. This booklet will help you clear-up any difficulties by showing you where you went wrong, then giving you extra practice in those areas.

But first, a word from your sponsor . . .



This is a do-it-yourself kit for learning about population relationships on food webs. <u>YOU ARE ONLY REQUIRED TO COVER THE MATERIAL FOR THE SKILLS WITH WHICH YOU HAD DIFFICULTY ON THE TEST</u>. These will be indicated on the chart entitled "Key to Skills", which is located on the next page.

The skills which gave you difficulty are circled in the first column of the chart.

Start with the LOWEST-NUMBERED SKILL, then turn to the page dealing with that skill. Read the information carefully, and think about what you are reading. After carefully answering and checking all the practice problems, and when you are sure you have achieved the skill, turn back to the key and write a "✓" beside that skill's number.

Then, turn to the page dealing with the next CIRCLED skill in the column and study that skill.

Continue until you have carefully covered the material for each of the circled skills.

On page 3.a. (following page 3) you can see how each of the skills is related to the others.

For all food webs shown in this booklet, arrows will always go from the prey species to the predator species:

rabbit ⟶ fox
(PREY) (PREDATOR)

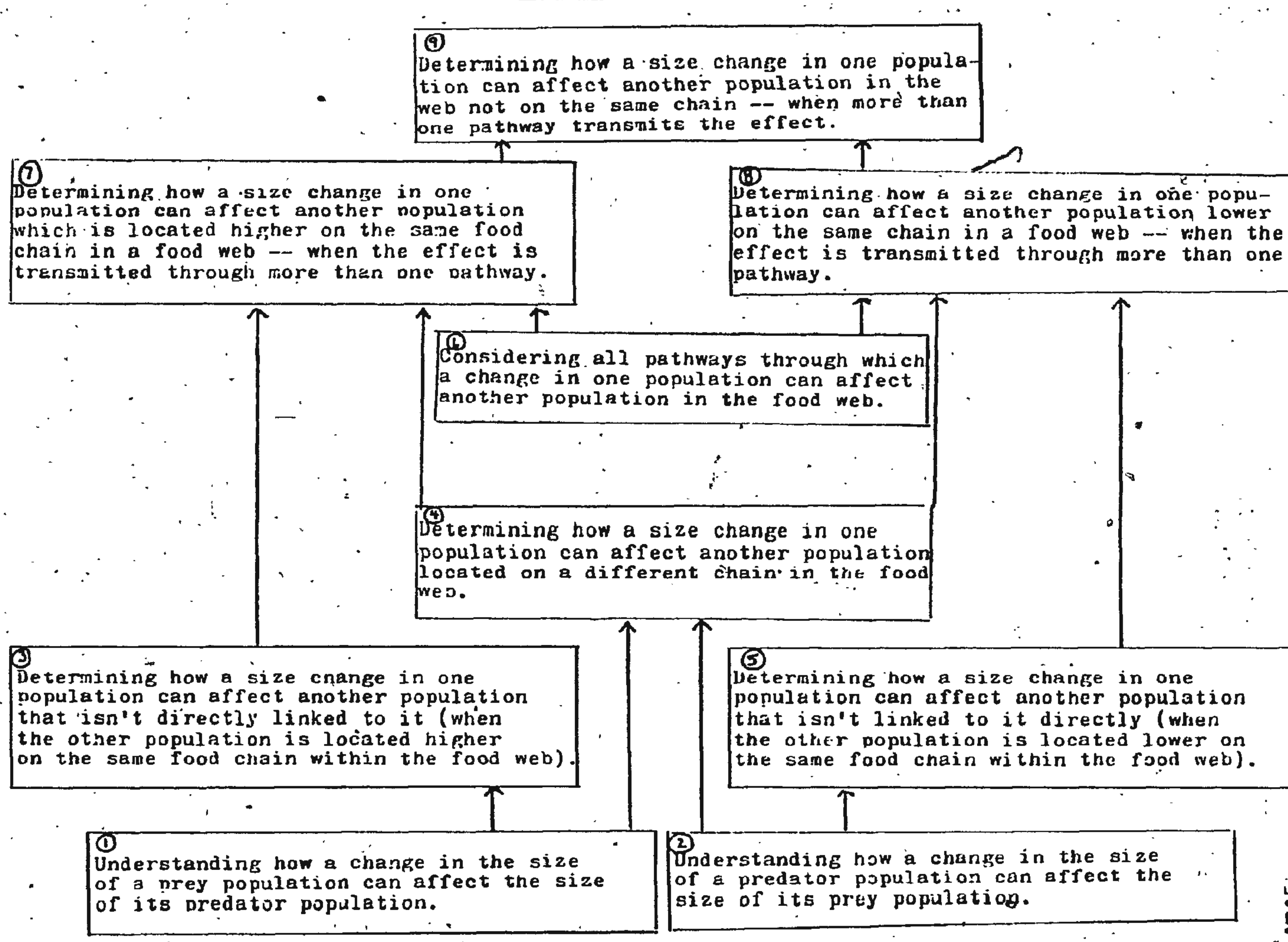
<u>Note</u>: You are only required to do those skills whose numbers are circled!

3.

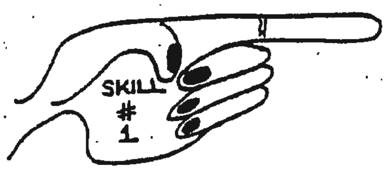
Key to Skills

Skill Number	Description of Skill	Page
1	Understanding how a change in the size of a prey population can affect the size of its predator population.	4
2	Understanding how a change in the size of a predator population can affect the size of its prey population.	8
3	Determining how a size change in one population can affect another population that isn't directly linked to it (when the other population is located higher on the same food chain within the food web).	12
4	Determining how a size change in one population can affect another population located on a different chain in the food web.	17
5	Determining how a size change in one population can affect another population that isn't linked to it directly (when the other population is located lower on the same food chain within the food web).	22
6	Considering all pathways through which a change in one population can affect another population in the food web.	27
7	Determining how a size change in one population can affect another population which is located higher on the same food chain in a food web -- when the effect is transmitted through more than one pathway.	33
8	Determining how a size change in one population can affect another population lower on the same chain in a food web -- when the effect is transmitted through more than one pathway.	38
9	Determining how a size change in one population can affect another population in the web not on the same chain -- when more than one pathway transmits the effect.	43

A Flow Chart of Skills



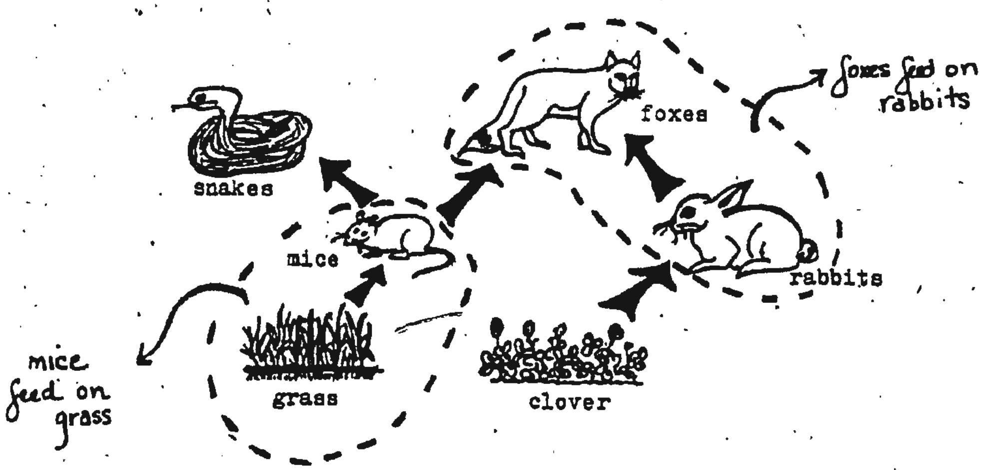
4.



UNDERSTANDING HOW A CHANGE IN THE SIZE OF A PREY POPULATION CAN AFFECT THE SIZE OF ITS PREDATOR POPULATION.

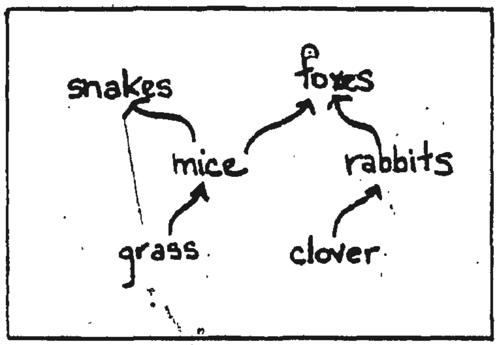
Almost every organism is preyed on (used as food) by some other organism. (Animals that feed on live organisms are called predators; the organisms that are eaten are called prey.)

Each link in a food web represents the eating of members of a prey population by those of a predator population:

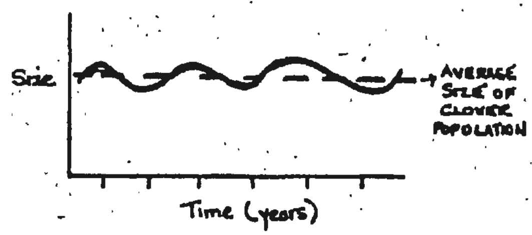


The food web shown above represents the feeding relationships in a very simple grassland community. If these feeding relationships have occurred for a number of years, the sizes of the populations in the community will stay fairly constant, generation after generation.

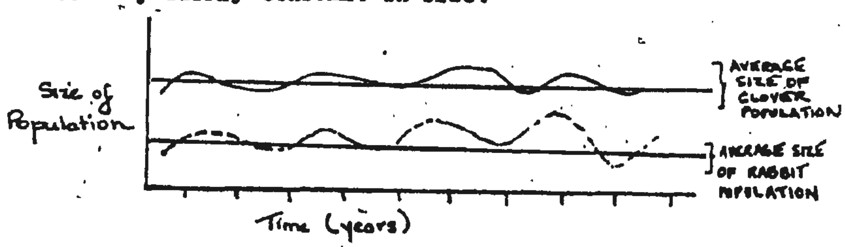
Looking at the food web, we see that the rabbit population feeds on a population of clover.



Over the years, the clover population may shift in size slightly, but tends to stay a certain "average" size.



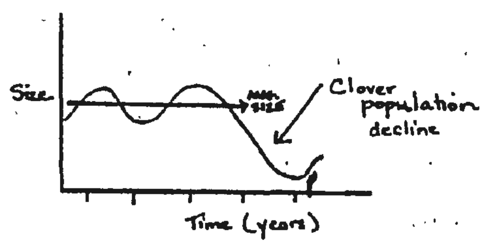
Since clover is the rabbit population's main food source, the rabbit population is only as large as what can be fed by the existing clover population. So, if the clover population stays fairly constant, the rabbit population will also tend to stay fairly constant in size.



BUT:

Suppose one year the clover population is greatly reduced by an unusually cold spring.

After years of being a fairly constant size, it suddenly becomes much smaller.



6.

Question: How will a sudden decline in the size of the clover population affect its predator, the rabbit population?

If there is a decrease in food (i.e. the clover population), some of the rabbits might die of starvation or leave the community to find a new area to live in. Since the number of rabbits in the original population is reduced, the size of the rabbit population has DECREASED.

Now take the **OPPOSITE** situation:

If some factor -- extremely good environmental conditions, for example -- causes the clover population to become larger than usual, how would this affect the predator population?

Answer: ______________________________

If you said the rabbit population would increase in size, you're right. Bravo!!

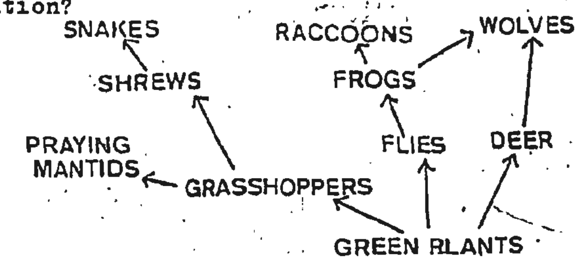
If there was an increase in the clover population, there would be more food for the rabbit population to eat. Thus, a larger population of rabbits could be supported by the larger clover population.

As you can see, when a prey population decreases, its predator population will decrease because of a lack of food. When a prey population increases, its predator will increase.

Understand? Turn the page to find out!

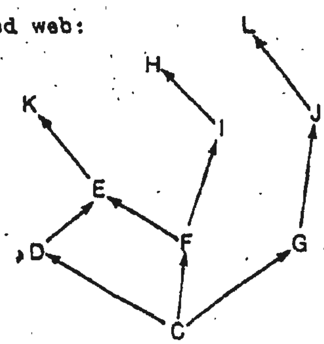
Test Yourself!

1. In the following food web, if the shrew population undergoes a sudden INCREASE, how will this affect the size of the snake population?



Answer: ______________________________

2. In the following food web:



If population I undergoes a sudden DECREASE in size, how will this affect the size of population H?

Answer: ______________________________

3. Explain the reason for your answer to question 2, above.

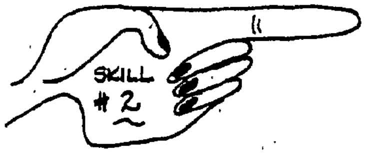
Answer: ______________________________

____

(Check all of your answers on page 49.)

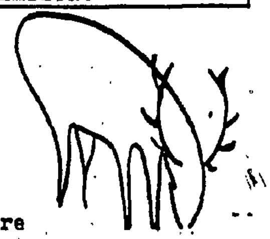
Once you have mastered this skill, turn back to the key on page 3. Find the next skill which has been circled and proceed.

8.



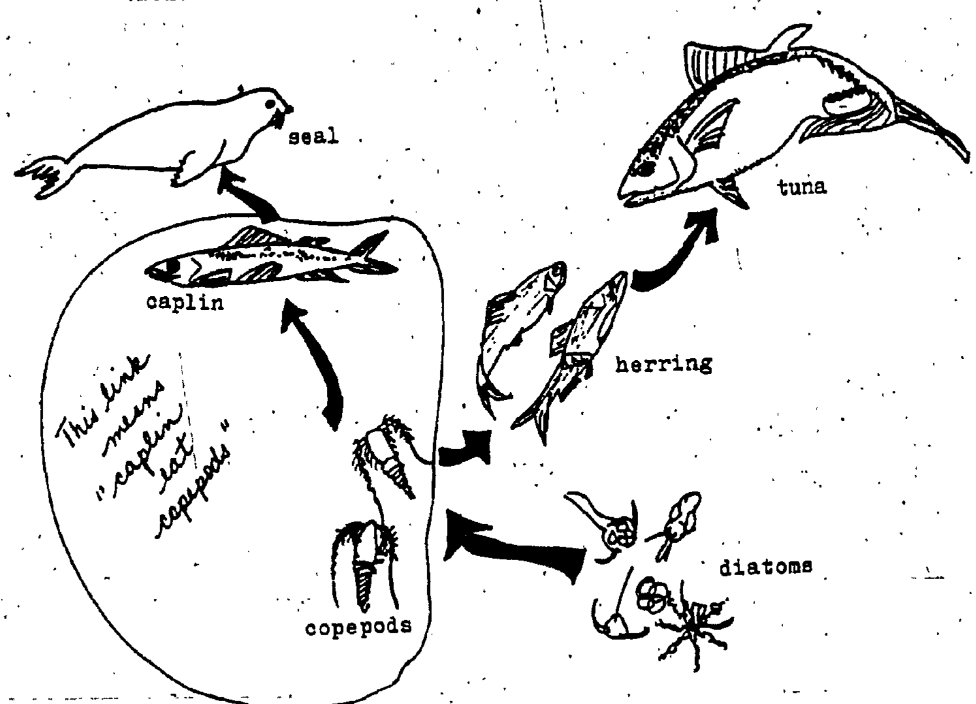
UNDERSTANDING HOW A CHANGE IN THE SIZE OF A PREDATOR POPULATION CAN AFFECT THE SIZE OF ITS PREY POPULATION.

All animals must eat to stay alive.



Animals that feed on live organisms are called predators; the organisms that are eaten are called prey.

Each link in a food web represents the eating of members of a prey population by those of a predator population:

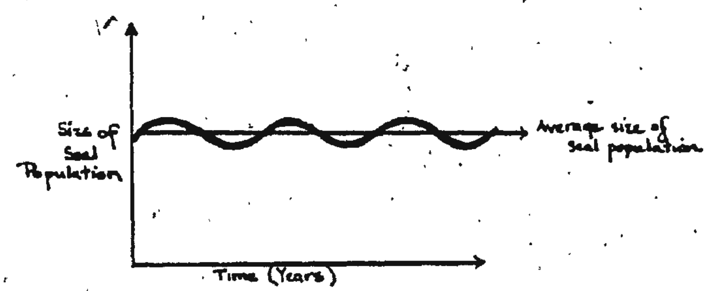


The food web shown above represents feeding relationships in a marine environment. If such feeding relationships occur for a number of years, the sizes of the various popula- stay fairly constant.

But what if one of the populations suddenly CHANGES in size?

9.

The food web indicates that seals eat caplin. Over the years, the seal population stays fairly constant, except for minor shifting in size:



Suppose that one year the seal population is greatly reduced -- this may have been caused by any number of factors. What effect will such a decrease in a predator population have on its prey, the caplin population?

If there were fewer seals feeding on caplin, FEWER caplin would be killed than are usually killed. As a result, the caplin population would grow larger than usual.

A DECREASE IN A PREDATOR POPULATION CAUSES AN INCREASE IN ITS PREY POPULATION.

Now take the OPPOSITE situation:

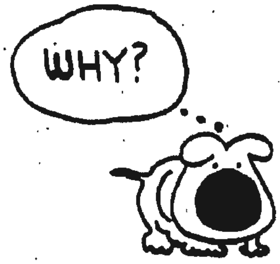
How does an INCREASE in a predator population affect its prey population? For example, use the marine food web(p8) to determine how an increase in the tuna population would affect the herring population; explain the reason for your answer.

Answer: ______________________________

Reason: ______________________________

10.

If you said the herring population would decrease in size, you're right. Bravo!! You're an ecological einstein!



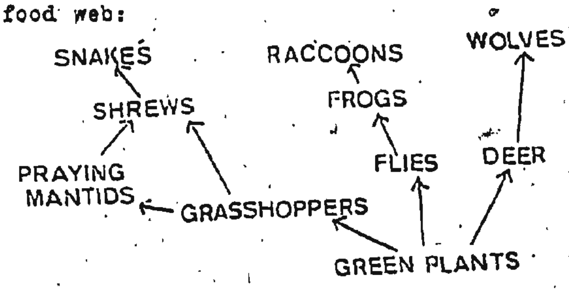
If there was an increase in the tuna population, they would eat more herring, which is their prey population. As a result more herring would be hunted than usual, and the population would DECREASE in size.

In summary, when a predator population decreases in size, the prey population tends to <u>increase</u> (because fewer will be killed for food). When a predator population increases in size, the prey population tends to <u>decrease</u> (because more prey are being killed than usually are, to feed the predators).

Understand? Turn the page to find out!

Test Yourself!

1. In the following food web:



If the frog population DECREASES in size, how will this affect the size of the fly population?

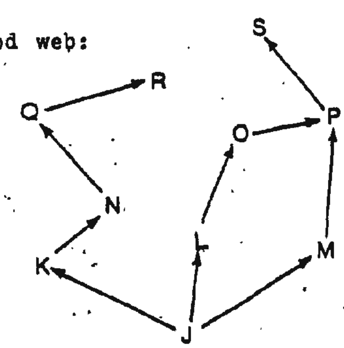
Answer: ______________________________

2. Explain the reason for your answer to question 1, above.

Answer: ______________________________

____

3. In the following food web:



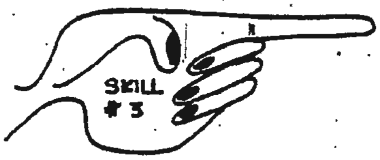
If population N undergoes a sudden INCREASE in size, how will this affect the size of population K?

Answer: ______________________________

(Check your answers on page 49.)

Once you have mastered this skill, turn back to the key on page 3. Find the next skill which has been circled and proceed.

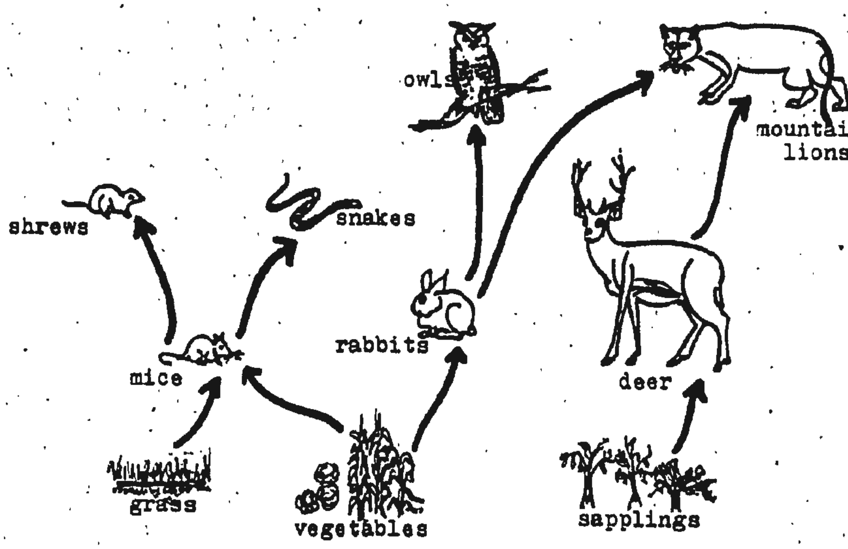
12.



DETERMINING HOW A SIZE CHANGE IN ONE POPULATION CAN AFFECT ANOTHER POPULATION THAT ISN'T LINKED TO IT DIRECTLY (WHEN THE OTHER POPULATION IS LOCATED HIGHER ON THE SAME FOOD CHAIN WITHIN THE WEB).

Missing Links???

Even though two populations may not be linked directly to each other within a food web, they can still affect each other. To see an example of how two such populations can be affected by each other, let's look at the following food web:

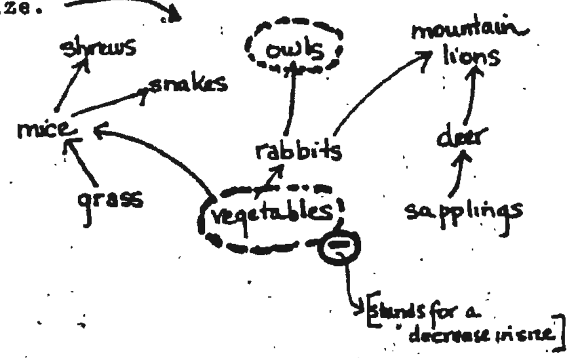


If some factor causes the vegetable population to decrease drastically, how would this affect the owl population?

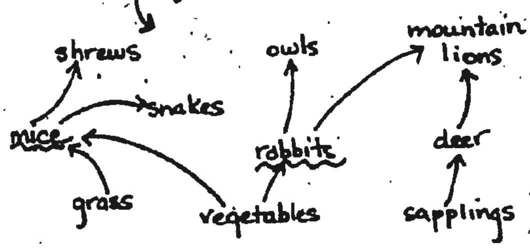
Turn the page, to find out

13.

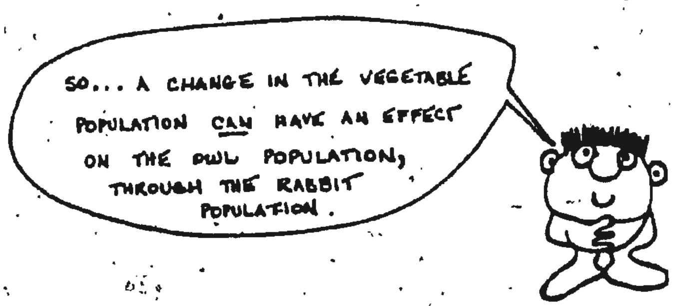
STEP ONE: First, locate the populations on the food web, and mark the population that has undergone the initial change in size.



STEP TWO: Notice how a decrease in the vegetable population can spread through the web, by observing the populations which are linked directly to the vegetable population.

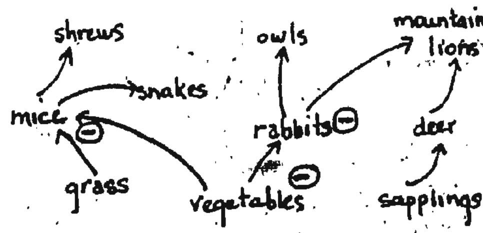


STEP THREE: A change in the vegetable population causes the mouse and rabbit populations to change. A change in the rabbit population will directly affect the mountain lion population and the owl population.



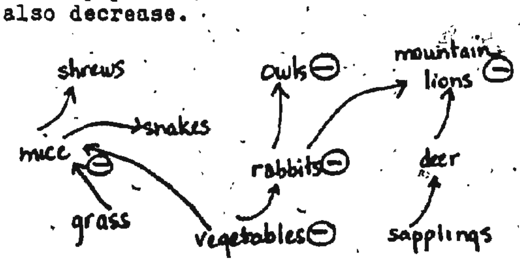
STEP FOUR: To determine what the effect on the owl population will be, if the vegetable population suddenly decreases, first determine how the rabbit population will be affected.

* Since rabbits are predators of the vegetable population, if the number of vegetables is suddenly decreased, the rabbit population that feeds on them will also suffer a decrease.



Now, determine how this change in the rabbit population will affect the owl population.

* Since owls are predators of the rabbit population, if the rabbit population decreases, the owl population that feeds on them will also decrease.



SUMMARY: A decrease in the vegetable population would cause the owl population to decrease, in time.

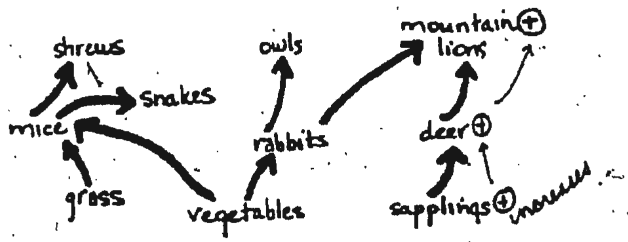
Now you try it! Using the same food web, determine how an increase in the sappling population would affect the mountain lion population.

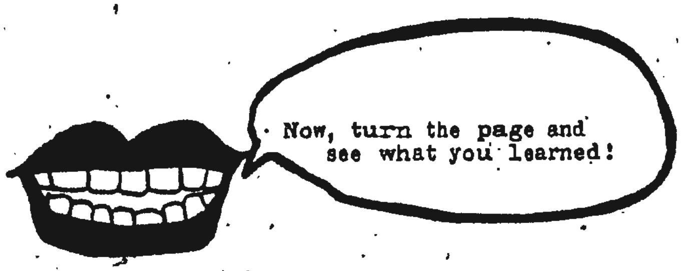
Answer: ______________________________.

15.

Answer: The effect of an increase in the sapling population on the mountain lion population is to cause it to increase.

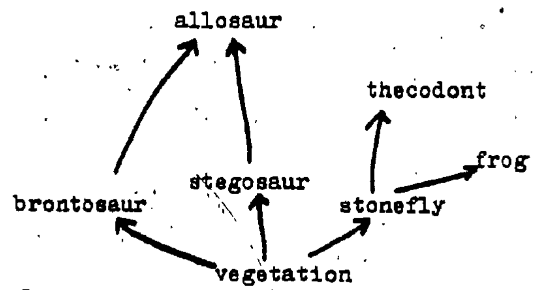
Here's why: An increase in saplings would cause an an increase in their predators, the deer population. An increase in the deer population would mean more prey for the mountain lion population -- causing it to increase.





Test Yourself!

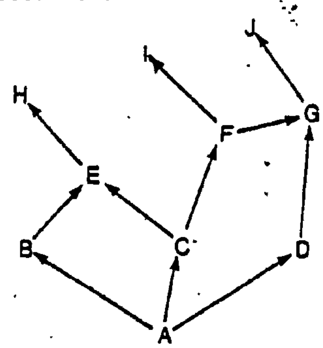
1. The following web represents feeding relationships in a prehistoric community:



Predict how a sudden decrease in vegetation (due to an impending ice age) would affect the size of the thecodont population.

Answer: ______________________________

2. In the following food web:



If population C suddenly increases, how will this affect the size of population I?

Answer: ______________________________

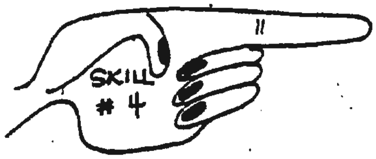
3. State the reason for your answer to question 2, above:

Reason: ______________________________

(Check your answers on page 49.)

Once you have mastered this skill, turn back to the key on page 3. Find the next skill which has been circled and proceed.

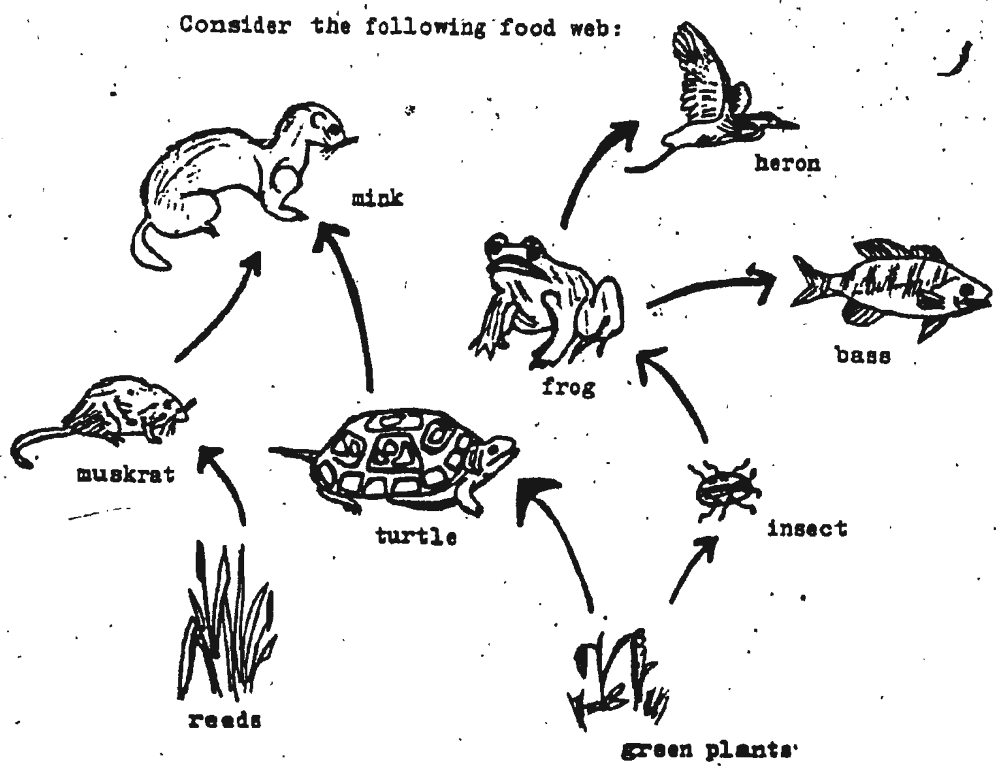
17.



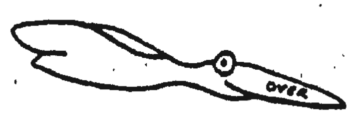
DETERMINING HOW A SIZE CHANGE IN ONE POPULATION CAN AFFECT ANOTHER POPULATION LOCATED ON A DIFFERENT CHAIN IN THE FOOD WEB.

Even though two populations in a food web may not be linked directly by an arrow, they can still have an effect on each other.

Consider the following food web:

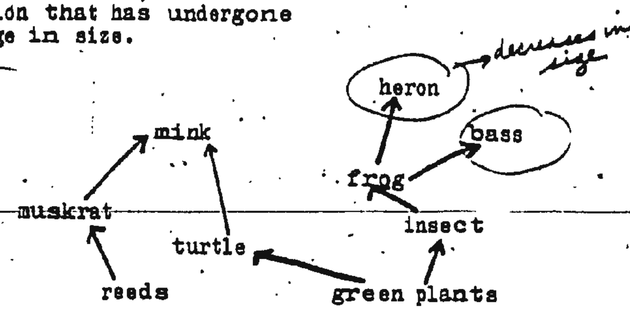


some factor causes the heron population to decrease drastically, how would this affect the bass population?

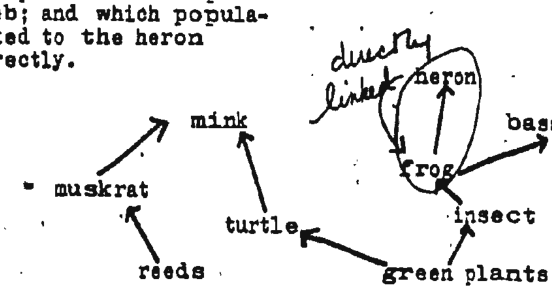


Even though the two populations are not directly linked, eventually one of the populations which changes as a result of the decrease in the heron population WILL have an effect on the bass population. To determine what the effect will be, follow these steps:

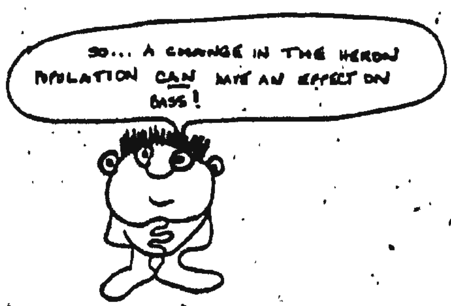
STEP ONE: First, locate the two populations on the food web, and mark the population that has undergone the initial change in size.



STEP TWO: Observe how a change (in this case, a decrease) in the size of the heron population can spread through the web; and which populations are linked to the heron population directly.



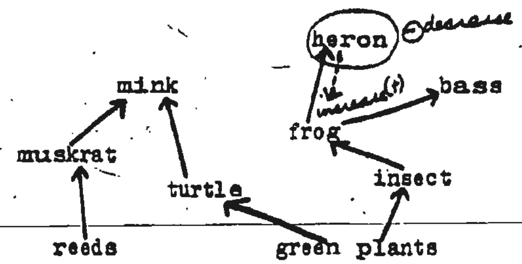
STEP THREE: A change in the heron population causes the frog population to change. This change in the fox population directly affects bass and insects.



NOW, to determine how the bass will be affected . . .

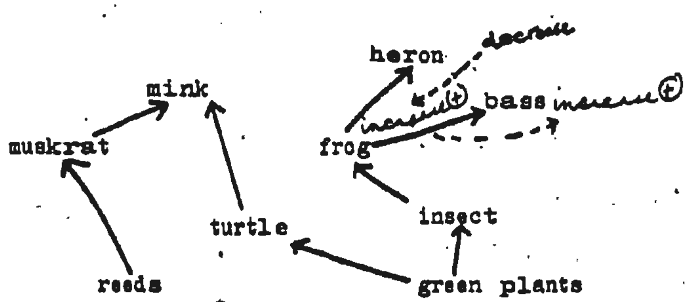
<u>STEP FOUR</u>: To determine the effect of a decrease in the heron population on the bass population, first determine how the frog population will be affected.

* Since herons are predators of the frog population a decrease in herons will cause an INCREASE in the frog population, their prey.

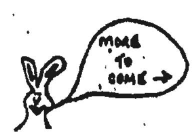


Now, determine how such a change in the frog population will affect the bass population.

* Since frogs are the prey of the bass population, an increase in the frog population will cause its predator, the bass population, to INCREASE.



Therefore, in this case, a <u>decrease</u> in the heron population resulted in an <u>increase</u> in the bass population.



20.

Using the same food web, determine how an INCREASE in the turtle population would affect the muskrat population.

Answer: ______________________________

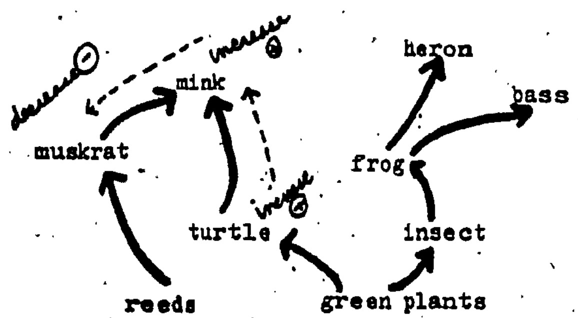
Let's see how you did:

1. If the turtle population increases, the effect on its predator, the mink population, will be to INCREASE.

2. If the mink population increases, the effect on its prey, the muskrat population, will be to DECREASE.

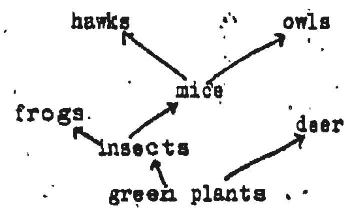
Therefore, an increase in the turtle population would cause the muskrat population to decrease.

(Note that we are ONLY taking into consideration the effects due to predator-prey relationships; this may, as a result, be a rather simple interpretation of a more complex situation.)



Test Yourself!

1. In the following food web:



If the mouse population suddenly increases, how will this affect the size of the frog population?

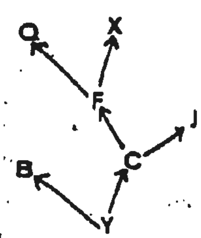
Answer: ______________________________

2. Explain the reason for your answer to question 1, above.

Answer: ______________________________

____

3. Consider the following food web:



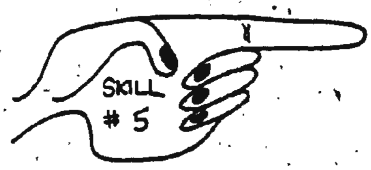
If population B suddenly decreases, how will this affect the size of population C?

Answer: ______________________________

(Check your answers on page 49.)

Once you have mastered this skill, turn back to the key on page 3. Find the next skill which has been circled and proceed.

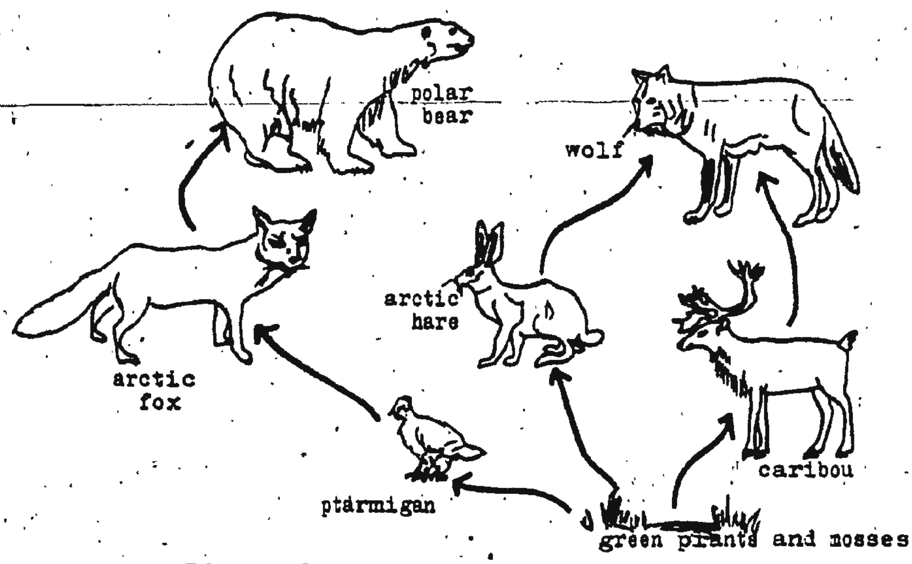
11.



DETERMINING HOW A SIZE CHANGE IN ONE POPULATION CAN AFFECT ANOTHER POPULATION THAT ISN'T LINKED TO IT DIRECTLY (WHEN THE OTHER POPULATION IS LOCATED LOWER IN THE SAME FOOD CHAIN WITHIN THE WEB).

What's the Connection??

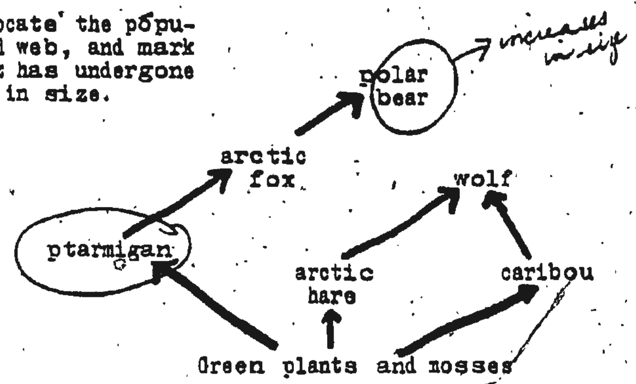
Even though two populations may not be linked directly to each other within a food web, they can still affect each other. To see an example of this, consider the following food web:



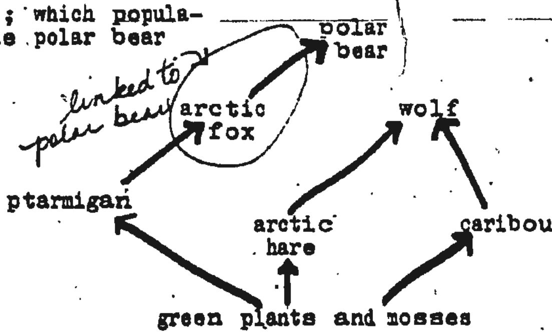
If some factor causes the polar bear population to increase in size, how would this affect the ptarmigan population?

Turn the page, to find out . . .

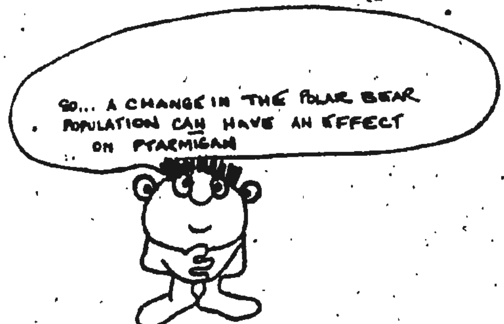
STEP ONE: First, locate the populations on the food web, and mark the population that has undergone the initial change in size.



STEP TWO: Observe how a change (in this case, an increase) in the size of the polar bear population can spread through the web; which populations are linked to the polar bear population directly.



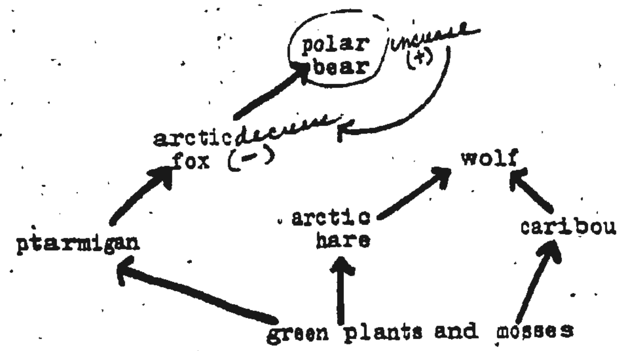
STEP THREE: A change in the polar bear population causes the fox population to change. A change in the fox population directly affects ptarmigans.



Now to determine how the ptarmigans will be affected . . .

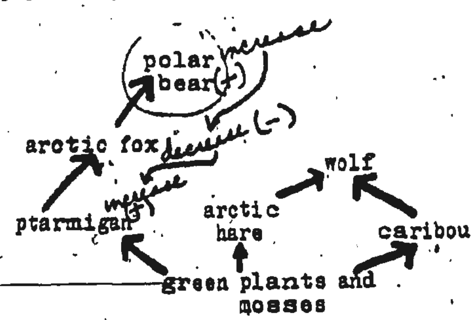
STEP FOUR: To determine the effect of an increase in the polar bear population on the ptarmigan population, first determine how the arctic fox population will be affected.

*Since polar bears are predators of the fox population, an increase in the polar bear population will cause a DECREASE in its prey, the arctic fox population.



Now, determine how this change in the fox population will affect the ptarmigan population.

* Since foxes are predators of the ptarmigan, if the fox population decreases, its prey, the ptarmigan will INCREASE in population size.



26.

Using the same food web, determine how a DECREASE in the polar bear population would affect the green plant and moss population.

Answer: ______________________________

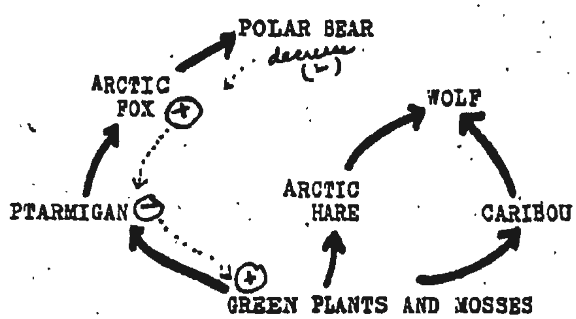
Let's see how you did:

1. If the polar bear population decreases, the effect on its prey, the fox population, will be to increase.

2. If the fox population increases, the effect on its prey, the ptarmigan population, will be to decrease.

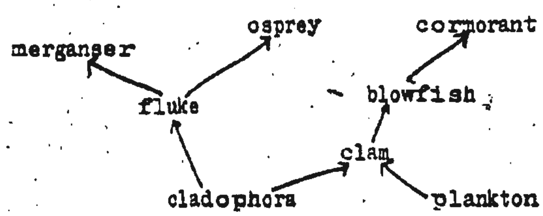
3. If the ptarmigan population decreases, the effect on its prey, the green plant and moss population will be to increase.

Therefore, a decrease in the polar bear population would cause the green plant and moss population to INCREASE.



Test Yourself!

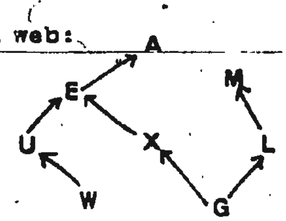
1. Consider the following food web:



If the cormorant population suddenly decreases, how will this affect the size of the clam population?

Answer: ______________________________

2. In the following food web:



If population A undergoes a sudden increase, how will this affect the size of population X?

Answer: ______________________________

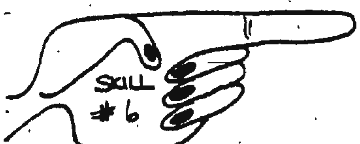
3. Explain the reason for your answer to question 2, above.

Answer: ______________________________

____

(Check your answers on page 47.)

> Once you have mastered this skill, turn back to the key on page 3. Find the next skill which has been circled and proceed.

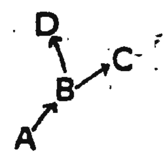


CONSIDERING ALL PATHWAYS THROUGH WHICH A CHANGE IN ONE POPULATION CAN AFFECT ANOTHER POPULATION IN THE FOOD WEB.

In previous problems dealing with the effect of a change in one population on another population in a food web, there was usually only one pathway in which the effect could travel.

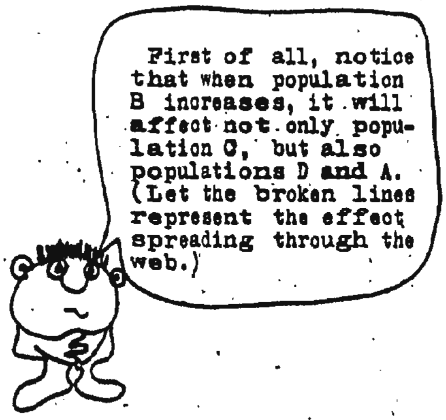
This is not always the case. In fact, for most food webs, this is RARELY the case. Food webs are used to represent feeding relationships in a community. They usually consist of a complex network of interconnections. As a result, there are numerous ways in which the effects of a change in one population can spread to a different population. In order to interpret food webs correctly, it is important to be aware of these, and to consider all of them.

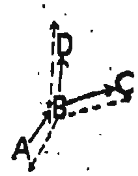
Consider the following simplified food web (each letter represents a different population):



Question

If population B increases in size, due to an extremely successful breeding season, how will this affect population C?

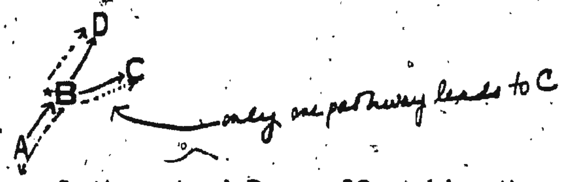




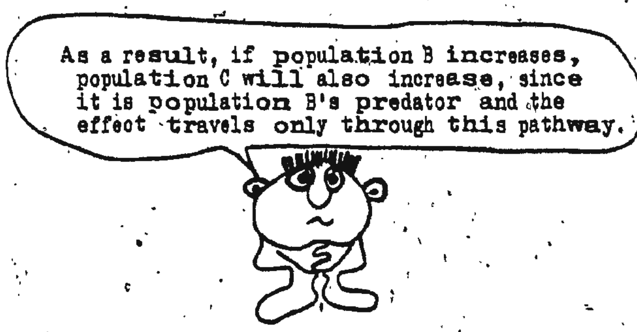
continued . . .

18.

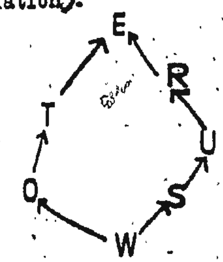
As indicated on the previous page, the effect of a change in population B can only reach population C from one pathway — directly from population B.



Even though populations A and D are affected by the increase in population B, there is no pathway from either of these populations, back to population C.

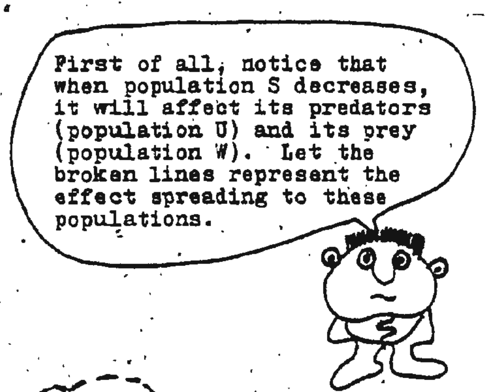


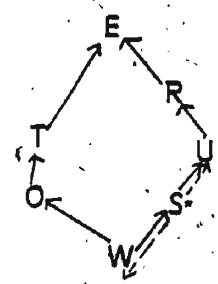
This time, we'll consider a different situation, in the following food web (again, each letter represents a different population).

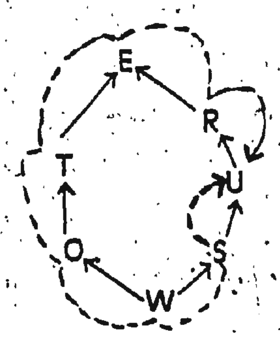


<u>QUESTION</u>: If <u>population S</u> suddenly decreases in size, how will this affect <u>population U</u>?

19.







In this food web, the effect of a decrease in population S can reach population U from two pathways:

1. From S to U directly.

2. From S to W to O to T to E to U !!!
   (this route may take longer)

The effect of a change in population S on population U MUST be determined by considering all possible pathways that the effect could arrive at population U.

If we consider only the first (shorter) pathway, we would conclude that a decrease in population S would cause its predator, population U, to decrease.

If we consider only the second (longer) pathway, what would we predict the effect to be on population U?

Take a moment now, to do this.

Answer: ____________________

30.

Check your answer here:

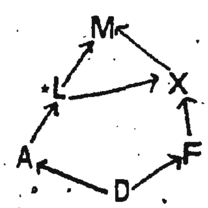
- a decrease in population S would cause an increase in its prey, population W
- an increase in W would cause an increase in its predator, population O
- an increase in O would cause an increase in its predator, population T
- an increase in T would cause an increase in its predator, population E
- an increase in E would cause a decrease in its prey, population R

and FINALLY, a decrease in population R would cause an increase in its prey, population U.

This route seems to suggest the effect is OPPOSITE to that of the other route's effect.

The most likely effect is a combination of the effects of the various pathways. Since in this case there were two possible effects, opposite to each other, the effects would tend to cancel out. In this case, a DECREASE in population S would probably result in no change in population U.

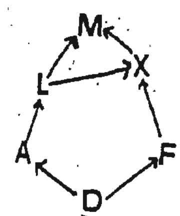
Sometimes there are more than two pathways to consider:



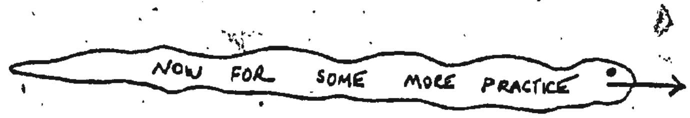
List the various pathways through which a change in population L might affect population X, in the space below:

There are three possible pathways:

1. L to X, directly
2. L to M to X
3. L to A to D to F to X

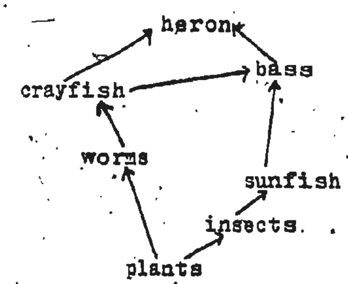


The skill of considering all possible effects from all possible directions is important in dealing with food webs. In a food web, as we have seen, there are often many complex interconnecting pathways between populations. It is these pathways that give a food web its stability -- so that often the effects of a drastic change in one part of the web are cancelled out before they drastically affect other populations in the web.



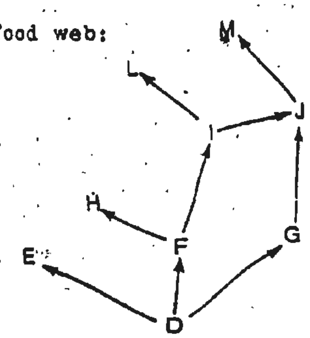
Test Yourself

1. For the following food web:



In the space below, write out all pathways through which a change in the size of the bass population can be passed along to the crayfish population.

2. For the following food web:

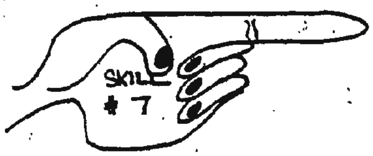


On the food web, circle the letters representing populations through which the effects of a change in population J will spread to population F.

(Check your answers on page 49.)

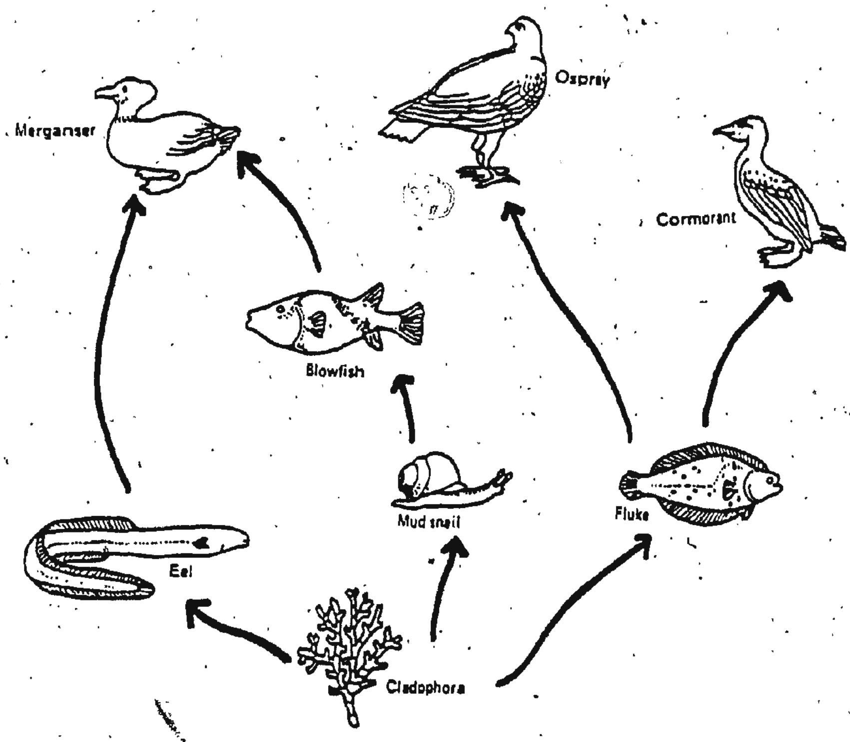
Once you have mastered this skill, turn back to the key on page 3. Find the next skill which has been circled and proceed.

33.



DETERMINING HOW A SIZE CHANGE IN ONE POPULATION CAN AFFECT ANOTHER POPULATION WHICH IS LOCATED HIGHER ON THE SAME FOOD CHAIN IN A FOOD WEB -- WHEN THE EFFECT IS TRANSMITTED THROUGH MORE THAN ONE PATHWAY.

Consider the following food web:

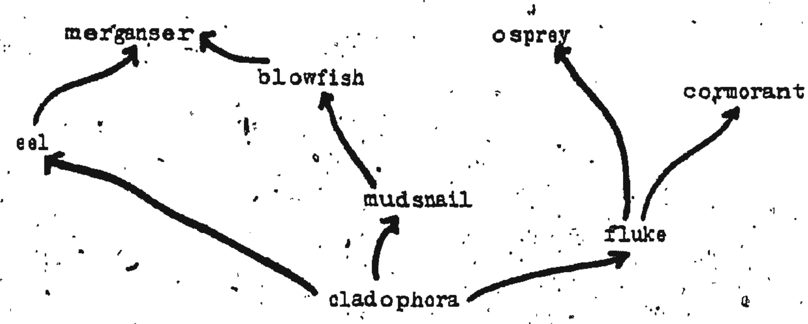


If the mudsnail population suddenly increases, how will this affect the merganser population?

Although these populations aren't directly linked by an arrow, it is clear that a change in the number of mudsnails could affect their predators, blowfish, which in turn would affect <u>their</u> predators, mergansers.

The solution to this problem is not so simple, however.

If you look at the web carefully, you will notice that the effect of a change in the mudsnail population can spread to mergansers by another pathway in the web:



What is the alternate pathway?

Answer: ____

____

____

The second pathway involves more populations. The effect could be passed in the following manner:

mudsnails to cladophora to eels to mergansers

In order to predict the effect of a change in one population on another population when more than one pathway connects them:

1. First, identify all possible pathways in which the effect could be passed from one population to the other.

2. For EACH pathway, determine the effect of the initial change on the population in question.

(continued →)

3. Sum the individual effects, to get a net effect. This is the best prediction of how the population will be affected in the long run.

For the food web we have been considering, determine the effect of an increase in the mudsnail population on the merganser population, using the guidelines below:

<u>Step one</u>: In the space below, list all possible pathways through which the effect might travel.

<u>Step two</u>: For each pathway listed above, determine the effect of an increase in mudsnails on mergansers.

<u>Step three</u>: Determine the overall net effect of an increase in mudsnails on mergansers, by summing individual effects.

(When you have finished step three, check your answer on the next page.)

36.

Check your answer here:

Step one:

1. mudsnail to blowfish to merganser
2. mudsnail to cladophora to eel to merganser

Step two:

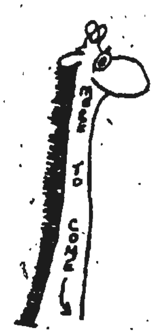
1. an increase in mudsnails would cause their predators, blowfish, to increase; this would cause their predators, mergansers to increase.

   Through this pathway, an increase in mudsnails results in an increase in mergansers.

2. an increase in mudsnails would cause their prey, cladophora, to decrease; this would cause their predators, eels, to decrease; which would cause their predators, mergansers, to decrease.

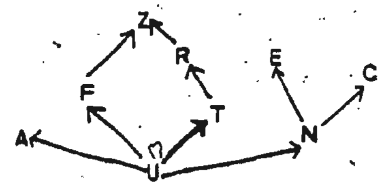
   Through this pathway, an increase in mudsnails results in a decrease in mergansers.

Step three: The net effect would be "no change" since the effects of the two pathways cancel each other out.



Test Yourself!

1. In the following food web:



If population T suddenly increases, how will this affect the size of population Z?

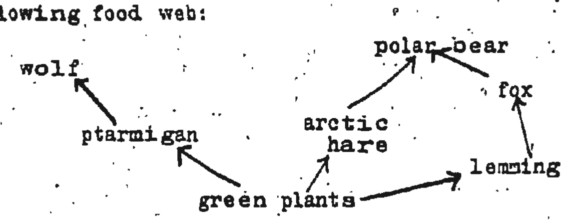
Answer: ______________________________

2. State the reason for your answer to question 1, above.

Answer: ______________________________

____

3. In the following food web:



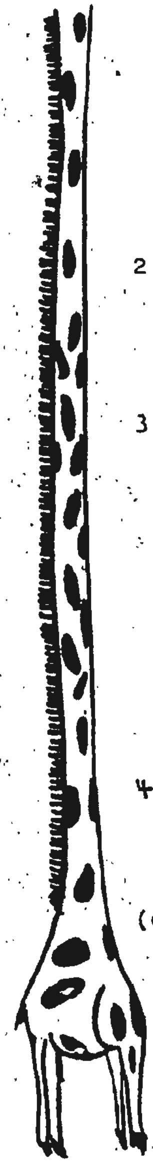
If the lemming population suddenly decreases, how will this affect the size of the polar bear population?

Answer: ______________________________

4. State the reason for your answer to question 3, above.

Answer: ______________________________

____



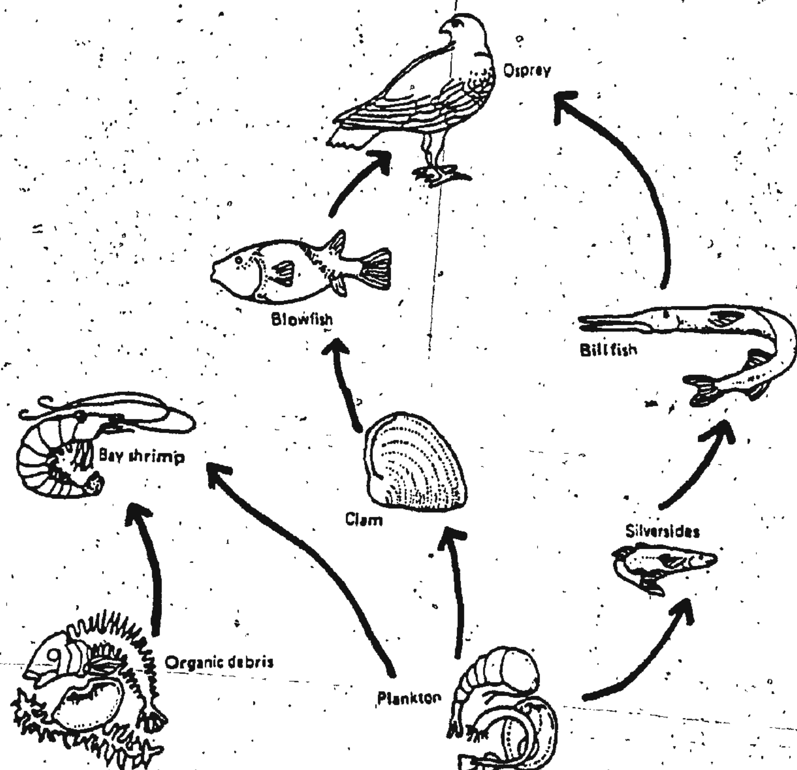
(Check your answers on page 50.)

Once you have mastered this skill, turn back to the key on page 3. Find the next skill which has been circled and proceed.

SKILL #8

DETERMINING HOW A SIZE CHANGE IN ONE POPULATION CAN AFFECT ANOTHER POPULATION LOCATED LOWER ON THE SAME CHAIN IN A FOOD WEB -- WHEN THE EFFECT IS TRANSMITTED THROUGH MORE THAN ONE PATHWAY.

Consider the following food web:



If the osprey population suddenly decreases, how will this affect the silversides population?

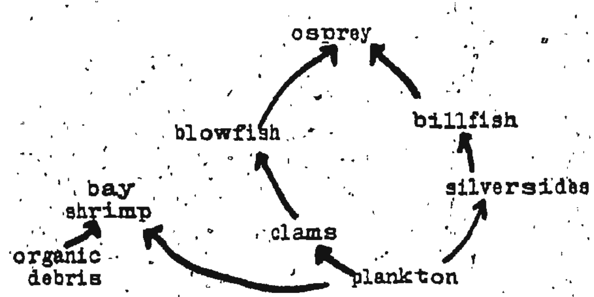
→

39.

Although the osprey and silverside populations aren't linked directly by an arrow, it is clear that a change in the osprey population could affect its prey, billfish, which in turn would affect its prey, silversides.

The solution to this problem is not so simple, however.

If you look at the web carefully, you will observe that the effect of a change in the osprey population can spread to the silverside population by another pathway.



In the space below, identify this other pathway:

Answer: ______________________________

____

The second pathway involves more populations than did the first pathway:

from osprey to blowfish to clams to plankton to silversides.

In order to predict the effect of a change in one population on another population when more than one pathway connects them, follow the steps indicated on the next page.

STEP ONE: First, determine all pathways through which the effect of a change in one population can move to another population.

STEP TWO: For EACH pathway, determine the effect of the initial change on the population in question.

STEP THREE: Sum the individual effects, to get an overall effect. This is the best predictor of how the population will be affected in the long run.

For the food web we have been considering, determine the effect of a decrease in the osprey population on the silverside population, using the guidelines below:

STEP ONE: List all possible pathways through which the effect could travel between the two populations.

STEP TWO: For each of the pathways listed above, determine the effect of a decrease in the osprey population on the silverside population.

STEP THREE: State the net overall effect of a decrease in the osprey population on the silverside population:

Check your answer on the next page, once you have completed all three steps.

Correct Answer:

Step one: 1. osprey to billfish to silversides

2. osprey to blowfish to clams to plankton to silversides

Step two: 1. A decrease in the osprey population would cause its prey, the billfish population, to increase; an increase in the billfish population would cause its prey, the silverside population, to decrease.

Therefore, for this pathway, a decrease in the osprey population results in a decrease in the silverside population.

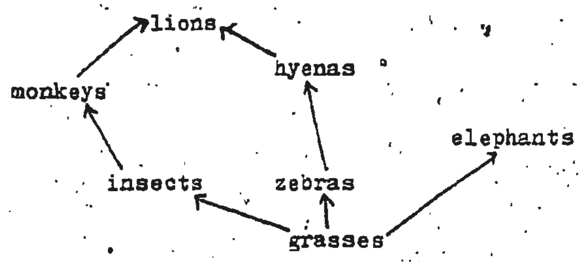
2. A decrease in the osprey population would cause its prey, the blowfish population, to increase; an increase in the blowfish would cause its prey, the clam population, to decrease. A decrease in the clam population would cause its prey, the plankton population, to increase; an increase in plankton would cause its predators, the silversides to increase.

Therefore, for this pathway, a decrease in the osprey population results in an increase in the silverside population.

Step three: The overall effect of a decrease in the osprey population is "no change" in the silverside population.

Test Yourself

1. In the following food web:



If the lion population suddenly increases, how will this affect the insect population?

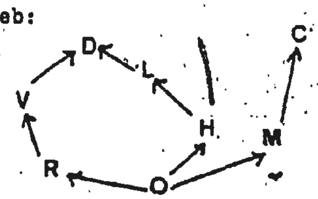
Answer: ____________________

2. State the reason for your answer to question 1, above.

Answer: ____________________

____

3. In the following food web:

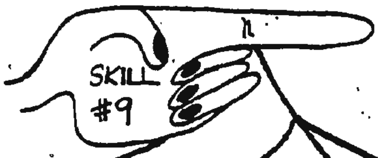


If population D suddenly decreases, how will this affect the size of population H?

Answer: ____________________

(Check your answers on page 50.)

Once you have mastered this skill, turn back to the key on page 3. Find the next skill which has been circled and proceed.



DETERMINING HOW A SIZE CHANGE IN ONE POPULATION CAN AFFECT ANOTHER POPULATION IN THE WEB WHICH IS NOT ON THE SAME CHAIN -- WHEN THE EFFECT IS TRANSMITTED THROUGH MORE THAN ONE PATHWAY.

A food web is a network of interconnecting predator-prey relationships. The populations in the web determine the linkages which give the web its stability.

Some relationships are more direct, and easily traced, than others. Regardless of how directly two populations interact, you can be sure that within a food web, every population has some influence on every other population in the web.

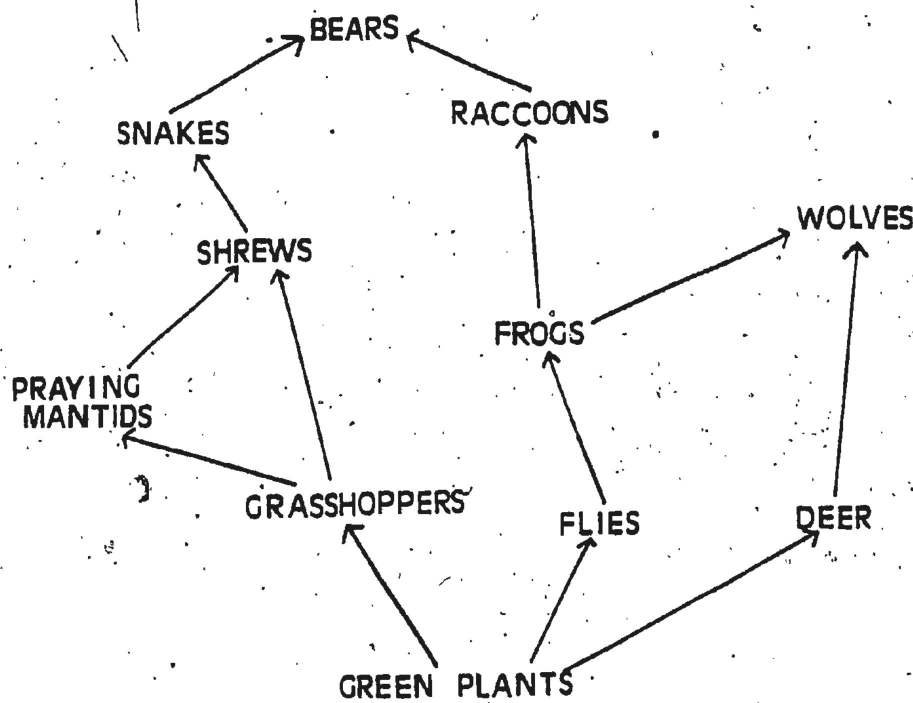
Just like a spider's web, when one part of the web is changed in some way, the effect will reverberate throughout the web -- to the farthest corners.

As you have probably discovered, interpreting food web relationships is not always easy. The more complex the web, the more difficult it is to trace effects through it.

In this section , we will study how to determine the effect of a change in one part of a web, on another population located in a different part of the web.

44

Consider the following food web:



If the raccoon population suddenly increases, how will this affect the shrew population?

To answer this question, it is necessary to see which populations are directly linked to the shrew population.

List these populations, and note which are predators and which are prey of the shrews, in the space below:

Answer: ______________________________

____

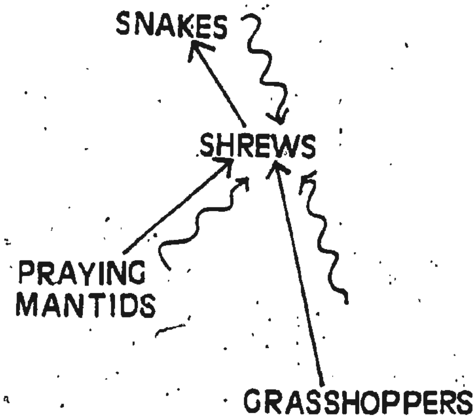
(check your answer on next page)

The overall effect of an increase in the raccoon population on the shrews will be felt through these three populations.

As you can see from the web, three populations directly affect the shrew population:

grasshoppers and praying mantids are prey of the shrews

snakes are predators of the shrews

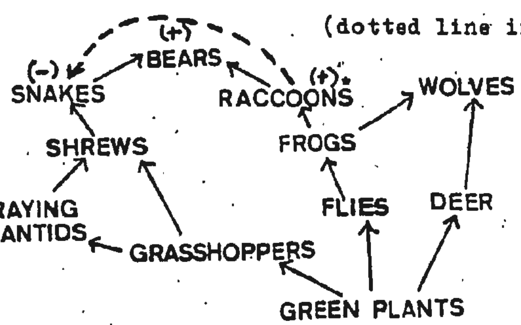


It is very important to FIRST determine the overall effect of an increase in the raccoon population on each of these populations, before we can determine the final effect on shrews.

***** To determine the overall effect of the increase in the raccoon population on snakes, grasshoppers or praying mantids it is necessary to consider ALL pathways through which these populations can be affected.

***** Then it is necessary to determine the net change in the population, by summing all the individual effects.

<u>Snakes</u>: Since the initial change happens to the raccoon population, the effect will spread to snakes by the following pathway:



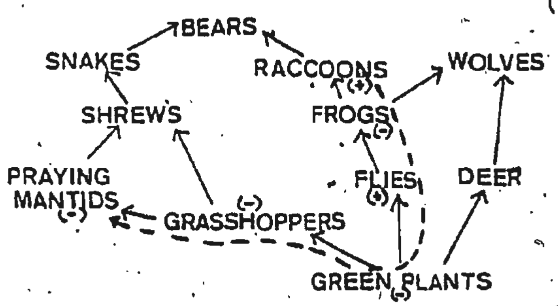
(dotted line indicates pathway; changes in population size are given in ()'s.)

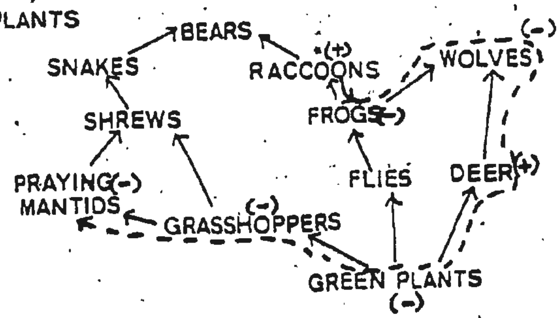
<u>Net effect</u>: decrease in snake population.

Praying mantids: The effect can spread from raccoons to praying mantids by two pathways:

(dotted line indicates pathway; changes in population size are given in ()'s)

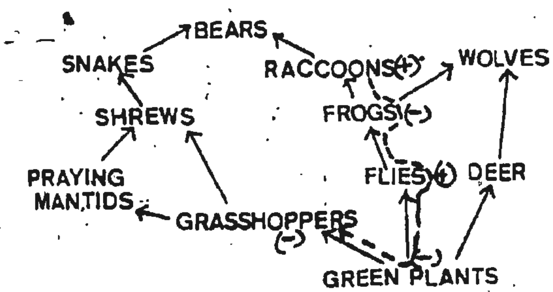
Net effect: decrease in praying mantid population (since both pathways indicated a decrease in praying mantids).

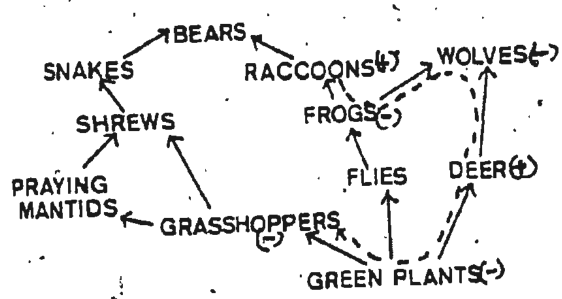




Grasshoppers: The effect can spread from raccoons to grasshoppers by two pathways:

Net effect: decrease in grasshopper population (since both pathways indicated a decrease in grasshoppers).

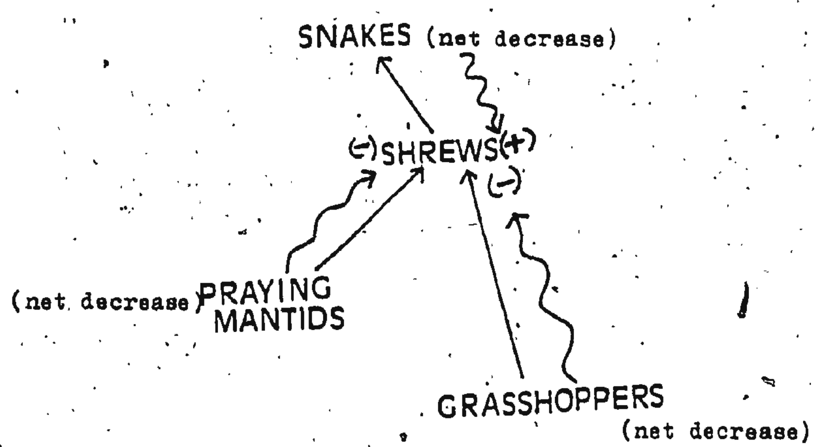




47.

To determine the net effect of an increase in the raccoon population on the shrew population, it is necessary to determine the effects of snakes, praying mantids and grasshoppers on the shrew population.

We have already determined how an increase in raccoons will affect snakes, praying mantids and grasshoppers. These results are shown below:



A decrease in snakes will cause an INCREASE in its prey, the shrew population. A decrease in grasshoppers will cause a DECREASE in its predator, the shrew population. A decrease in praying mantids will cause a DECREASE in its predator, the shrew population.

As a result, the shrew population would undergo a net decrease in size (since there were more individual decreasing effects, than increasing effects).

SUMMARY: To determine the effect of a change in "population A", on another population located in a different part of the web (call this population "B"):

1. Identify the populations directly linked to population B.
2. For each of these populations, determine the net effect of a change in population A by: (i) considering all pathways, then (ii) summing individual effects to obtain a net effect
3. Determine the net effect on population B by considering the individual effects from the populations directly linked to it.

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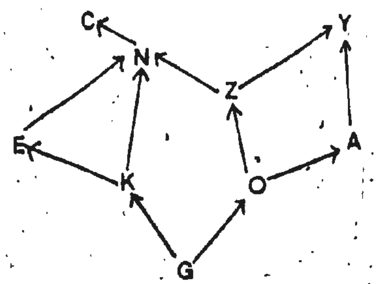
Test Yourself

1. Consider the following food web:



If population Y suddenly increases, how will this affect the size of population K?

Answer: ______________________________

2. Explain the reason for your answer to question 1, above.

Answer: (use the space below)

(Check your answers on page 50.)

Answers to Test Yourself! Questions

page 7
1. the snake population would increase
2. population H will decrease
3. Since population I is the food of population H, if there is a decrease in the food supply, some of the animals will die or leave the population.

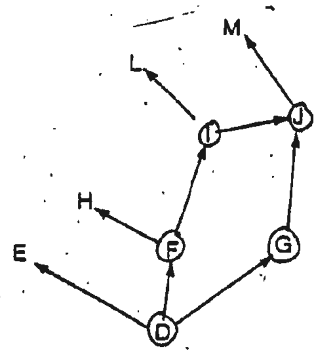
page 11
1. the fly population would increase
2. Since frogs are the predators of flies, if the frog population decreases, fewer flies will be killed for food — so the population will tend to increase.
3. population K would decrease

page 16
1. the thecodont population would decrease
2. population I will increase
3. If population C increases, there will be enough food for more predators, so population F will increase. When F increases it will in turn allow I to increase, since there is more food available than there was before.

page 21
1. the frog population would decrease
2. If the mouse population increases, it will eat more insects, so the insect population will decrease. If the insect population decreases, its predator, the frog population will be caused to decrease.
3. population C will increase

page 26
1. the clam population would decrease
2. population X would increase
3. If population A increases, it will kill more prey -- so population E will decrease. If population E decreases, it will not kill as many prey as usual, so population X will tend to increase.

page 32
1. - bass to crayfish, directly
   - bass to heron to crayfish
   - bass to sunfish to insects to plants to worms to crayfish
2.



J → I → F
J → G → D → F
pathways involved

(continued)

page 37
1. Z would probably remain the same size
2. The effect of a change in T can travel to population Z by two pathways:
   - -T to R to Z
   - -T to U to F to Z

   In the first pathway, the effect is for Z to increase; in the second, the effect is for Z to decrease. Since these two effects cancel out, the net effect is for Z to remain the same size, in the long run.
3. The polar bear population would remain the same size.
4. The effect of a change in lemmings can travel to polar bears by two pathways:
   - -lemmings to foxes to polar bears (causes an increase)
   - -lemmings to green plants to arctic hares to polar bears (causes polar bears to decrease)

   The two pathways give opposing effects, so the net effect is no change.

page 42
1. the insect population would remain the same size.
2. The effect of a change in lions can travel to insects by two pathways: -lions to monkeys to insects (causes an increase)
   -lions to hyenas to zebras to grasses to insects (causes a decrease in the insect population)

   Since these two effects are opposing, the net effect is no change in the insect population.
3. no net change in population H

page 48
1. population K will decrease.
2. The net effect of a change in population Y on population K will ultimately pass to population K via populations E,N, and G. So, the net effects of a change in population Y must first be determined for each of these, by considering all possible routes.

   population N: - Y to Z to N (causes N to decrease)
   - Y to A to O to Z to N (causes N to increase)
   NET EFFECT: no change

   population E: - Y to Z to N to E (causes E to increase)
   - Y to A to O to Z to N to E(causes E to decrease)
   NET EFFECT: no change

   population G: - Y to Z to O to G (causes G to decrease)
   -Y to A to O to G (causes G to decrease)
   NET EFFECT: G will decrease

   The net effect of the change in Y on population K will depend on individual effects passed on from populations N, E and G. Since neither N nor E change in size, they will not cause a change in K, but G will cause K to decrease.
   Therefore, the net effect on population K is for K to decrease.

APPENDIX D

TEST SCORES ON THE PRETEST AND POSTTEST

1 = correct response
0 = incorrect response
9 = missing information

Student	Pretest									Posttest								
Student	Skill 1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
No. Item	2 13	5 18	6 15	10 16	4 7	12 17	1 14	9 11	3 18	4 11	2 17	5 18	6 10	1 16	7 14	3 12	9 13	8 15
1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	9 9	9 1	9 9	0 0	9 1	1 1	0 9	0 9	0 0
2	9 1	1 1	9 1	1 9	1 1	9 9	9 0	0 0	0 9	1 1	9 1	1 9	1 1	9 1	9 1	9 1	9 1	9 1
3	9 1	1 1	9 1	1 9	1 1	9 1	9 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
4	9 1	1 1	9 1	1 9	1 1	9 9	9 0	1 0	0 0	1 1	9 1	1 9	1 1	9 1	9 1	1 1	1 1	9 1
5	1 1	1 1	1 1	1 1	1 1	0 1	0 0	0 0	0 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
6	1 1	1 1	1 1	1 1	1 1	9 1	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
7	1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 9	1 1	9 1	1 1	1 1	1 1	9 9	0 0	0 0	9 0
8	1 1	1 1	9 1	1 9	1 1	9 1	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	9 9	1 1	1 1	0 0
9	1 1	1 9	9 1	9 9	0 1	0 0	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	0 1	0 0	0 0	0 0
10	0 1	1 1	1 1	1 1	1 1	9 0	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
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12	9 1	1 9	9 1	1 9	0 9	0 0	0 0	0 0	0 0	9 1	9 1	1 0	9 9	9 1	0 1	0 0	0 0	0 0
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14	9 0	1 1	1 1	1 1	0 0	9 9	0 0	0 0	0 0	1 1	1 1	0 0	0 1	0 0	0 0	0 0	0 0	0 0
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16	1 1	1 1	1 9	1 1	0 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0
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22	1 1	9 9	0 0	9 9	9 0	9 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	0 9	0 0	0 0	0 0
23	0 0	9 9	9 0	9 9	9 9	9 9	0 0	0 0	0 9	1 1	9 9	9 9	0 0	9 0	0 0	9 0	0 0	0 0
24	1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
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26	1 1	1 1	1 0	0 9	0 0	9 0	0 0	0 0	0 9	1 1	1 1	1 9	1 1	9 1	1 1	0 0	0 0	9 0
27	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	0 0	1 1	1 1	9 1	1 0	1 1	1 1	0 0	0 0	0 0
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32	9 1	1 1	9 1	1 9	1 1	9 9	9 0	0 0	0 9	1 1	9 1	1 9	1 1	9 1	9 9	1 1	0 1	9 0
33	9 1	1 1	9 1	1 9	0 1	9 9	9 0	9 0	0 9	1 1	9 1	1 9	1 1	9 1	0 0	0 0	0 0	0 0
34	1 1	1 1	1 1	1 1	9 1	0 0	0 0	0 0	0 0	1 1	1 1	9 1	1 1	1 1	0 0	0 0	0 0	0 0
35	1 1	1 1	1 9	1 9	1 1	9 9	0 0	0 0	0 9	9 1	1 1	9 1	1 1	0 1	0 0	0 0	0 0	0 0

APPENDIX : (Continued)

		Pretest									Posttest								
Student	Skill	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
No.	Item	2 13	5 18	6 15	10 16	4 7	12 17	1 14	9 11	3 18	4 11	2 17	5 18	6 10	1 16	7 14	3 12	9 13	8 15
36		9 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
37		1 1	9 9	1 1	1 1	9 9	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
38		9 1	1 9	9 1	9 9	1 9	9 9	0 0	0 0	0 0	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
39		1 1	1 1	1 0	1 1	1 1	9 9	0 0	0 0	0 0	1 1	1 1	1 9	1 1	1 1	9 9	0 9	9 0	0 0
40		1 1	1 1	1 1	1 1	1 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 0	1 0	1 0	0 0
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43		9 1	1 1	1 1	9 9	9 1	9 0	9 0	0 0	0 9	1 1	1 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0
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47		1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0
48		1 1	1 1	1 1	0 1	1 1	9 1	0 0	0 0	9 9	1 1	1 1	1 1	0 1	1 1	9 1	0 0	0 0	0 9
49		9 1	1 1	1 1	1 0	0 0	1 0	0 0	0 0	0 0	1 1	1 1	9 1	0 0	1 1	1 1	0 0	0 0	0 0
50		9 1	1 1	9 9	9 9	9 1	9 9	9 0	9 9	0 9	1 1	1 1	1 0	1 1	1 1	0 0	0 0	9 9	0 9
51		1 1	1 1	1 1	1 1	1 1	1 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	1 1	1 1	0 0
52		1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
53		1 1	1 1	0 1	9 9	0 1	0 0	0 0	0 0	0 0	1 1	1 1	0 0	9 9	0 0	0 0	0 0	0 0	0 0
54		1 1	9 9	1 0	0 0	0 0	0 0	0 0	0 0	0 0	1 1	9 9	9 9	0 9	1 0	0 0	0 1	0 9	0 0
55		1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
56		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	0 0	0 9	0 0	0 0
57		9 1	9 9	9 0	0 9	9 9	9 9	9 0	9 9	9 9	9 1	9 0	0 9	0 9	9 0	9 9	9 0	9 9	9 0
58		1 1	1 1	1 0	9 9	1 0	0 0	0 0	0 0	0 0	1 1	1 1	9 1	9 9	1 1	0 0	0 0	0 0	0 0
59		1 1	1 1	1 1	1 1	0 1	0 0	0 0	0 0	0 0	9 9	9 1	9 9	0 0	9 1	9 9	0 0	0 0	0 0
61		1 9	1 1	1 0	1 1	1 1	0 0	0 0	0 0	0 0	1 1	9 1	1 0	9 1	1 1	0 0	0 1	1 0	0 0
62		1 9	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	1 1	1 1	1 1
63		1 9	1 1	1 1	1 1	9 1	0 0	0 0	0 0	0 0	1 1	9 1	1 9	1 1	9 1	1 1	1 1	1 1	9 1
64		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	1 1	1 1	0 0
65		1 1	1 1	1 1	1 1	1 0	0 0	0 0	0 0	0 0	1 1	9 1	1 9	1 1	1 1	1 1	1 1	1 1	9 0
66		1 1	1 1	1 0	1 1	1 1	9 9	0 0	0 0	0 0	1 1	9 1	1 9	1 0	9 1	9 9	1 1	1 1	9 0
67		1 1	1 1	1 9	9 9	1 1	9 1	0 0	0 0	0 0	1 1	9 1	1 9	1 1	9 1	9 9	1 1	1 1	0 1
68		1 1	1 9	0 1	9 0	9 1	1 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 0	0 0
69		1 1	9 1	9 1	1 1	0 9	0 0	0 0	0 0	0 0	1 9	1 1	1 1	1 1	1 1	1 1	1 1	1 0	0 1
70		9 0	0 9	0 0	0 9	0 0	9 1	0 0	0 0	0 9	1 1	9 1	1 9	1 1	9 1	9 0	1 1	0 1	9 0

APPENDIX : (Continued)

Student No.		Pretest									Posttest								
	Skill	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
	Item	2 13	5 18	6 15	10 16	4 7	12 17	1 14	9 11	3 18	4 11	2 17	5 18	6 10	1 16	7 14	3 12	9 13	8 15
71		1 1	1 1	1 9	1 1	1 0	9 0	0 0	0 0	0 0	1 1	1 1	1 9	0 1	9 1	1 1	0 0	0 0	0 0
72		0 0	1 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 1	9 1	1 9	1 1	1 1	0 0	0 0	0 0	0 0
73		0 1	1 1	1 1	1 1	0 1	9 9	0 0	0 0	0 9	0 9	1 1	1 1	1 0	0 1	9 9	0 0	0 0	0 0
74		1 1	1 1	1 1	1 1	1 1	1 0	0 0	0 0	0 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
75		1 9	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	9 1	1 9	1 1	9 1	9 9	1 1	9 1	9 0
76		0 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
77		1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 9	0 0	1 1	1 1	1 1	1 1	1 1	1 9	9 9	9 9	0 0
78		1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	9 1	1 9	1 1	9 9	9 1	1 1	9 1	9 1
79		1 1	1 1	1 1	1 1	0 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
80		9 0	9 9	9 9	9 0	0 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 0	1 1	1 1	1 1	0 1	0 1
81		0 1	1 1	0 9	1 0	1 1	9 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	9 9	9 9	0 0
82		1 1	1 1	1 1	9 9	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 9	1 1	1 1	0 9	1 1	1 1	0 0
83		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	1 1	1 1	0 0
84		1 1	1 1	1 1	9 9	9 1	0 0	0 0	0 0	0 0	9 1	1 1	9 1	1 1	1 1	0 0	0 0	0 0	0 0
85		1 1	1 1	9 1	9 9	1 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0
86		1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
87		1 1	1 1	1 1	1 1	0 1	9 0	0 0	0 0	0 0	1 1	9 1	1 1	1 1	1 1	0 1	9 9	9 0	0 0
88		1 1	1 1	1 1	1 1	1 1	9 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
89		1 0	1 1	1 0	9 9	0 0	0 0	0 0	0 0	0 0	1 1	9 1	9 9	0 0	9 1	9 9	0 0	0 0	0 0
90		1 1	1 1	1 1	1 1	1 1	0 1	0 0	0 0	0 0	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
91		1 1	0 0	1 1	0 0	0 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 0	1 0	1 1	1 1	1 1	0 0
92		1 1	1 1	1 0	1 1	9 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	0 1	1 1	1 0
93		9 0	1 0	9 0	0 0	0 0	0 0	0 0	0 0	0 0	9 9	1 1	9 0	0 9	1 1	0 0	0 0	0 0	0 0
94		9 9	1 1	0 9	9 9	9 0	9 9	0 0	0 0	0 0	1 1	1 1	1 1	9 9	1 1	1 1	1 1	0 0	1 0
95		9 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
96		1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	0 1	1 1	0 0
97		1 1	1 1	1 1	0 1	1 9	0 1	0 0	0 0	0 0	1 1	1 1	1 [illegible]	1 1	1 1	9 1	0 0	0 1	0 0
98		1 1	1 1	1 1	1 1	9 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 1
99		0 1	1 1	0 1	1 0	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
100		1 1	1 1	1 1	1 1	1 1	9 0	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 1	0 0
101		1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	9 9
102		0 9	9 1	9 9	9 9	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	9 9	1 1	0 0	0 0	0 0	0 0
103		1 1	1 1	1 1	1 1	1 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
104		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	9 0	1 1	0 1	1 9	1 1	9 1	9 1	0 1	1 0	0 0
105		1 1	1 1	1 1	1 1	1 1	1 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 0	0 1	0 0

APPENDIX : (Continued)

		Pretest									Posttest								
Student	Skill	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
No.	Item	2 13	5 18	6 15	10 16	4 7	12 17	1 14	9 11	3 18	4 11	2 17	5 18	6 10	1 16	7 14	3 12	9 13	8 15
106		0 1	1 1	0 1	1 0	1 1	9 9	0 0	0 0	0 0	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
107		0 0	1 1	0 0	9 9	1 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 0	1 1	0 1
108		1 1	1 1	1 1	1 9	0 1	9 9	0 0	0 0	0 0	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
109		1 1	1 1	9 1	1 1	1 1	0 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	0 0	1 1	1 1	1 0
110		1 1	9 9	1 1	9 9	0 9	9 9	0 0	0 0	0 0	1 1	9 1	19	1 1	9 1	9 1	9 1	9 1	9 1
111		1 1	1 1	1 1	9 1	1 1	1 1	0 0	0 0	0 0	1 1	9 1	1 9	1 1	9 1	1 1	1 1	1 1	9 1
112		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 0
113		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 1	0 0	1 1	1 1	1 1	1 1	1 1	1 1	0 0	1 1	0 0
114		1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	1 9	1 1	1 1
115		9 1	1 1	1 0	1 9	1 0	9 9	0 0	0 0	0 0	1 1	1 1	1 9	1 1	1 1	9 9	9 9	9 9	0 0
116		1 1	9 0	0 9	1 9	9 9	0 0	0 0	0 0	0 0	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
117		1 1	1 1	1 1	1 0	1 1	9 9	0 0	0 0	0 0	1 1	9 1	1 9	1 1	9 1	1 1	1 1	1 1	9 1
118		1 1	1 1	0 1	1 1	0 1	0 0	0 0	0 0	0 0	1 1	9 1	1 9	1 1	9 1	9 1	1 0	9 1	9 0
119		1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	1 1	9 0	1 9	9 1	1 1	1 1	1 1	1 1	9 1
120		1 1	1 1	1 1	1 1	0 0	9 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	9 9	9 9	1 1
121		1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
122		1 1	1 1	1 1	1 1	0 0	0 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
123		9 1	1 1	1 1	9 0	0 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 1	1 1	0 0	0 9
124		1 1	9 1	0 0	1 1	0 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	9 9	9 9	9 9
125		1 1	9 9	9 1	1 9	9 0	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 1
126		1 1	1 9	1 1	1 1	0 9	0 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0
127		0 1	9 0	9 1	0 0	9 1	0 0	0 0	0 0	9 0	1 1	9 9	9 9	1 9	9 9	0 0	0 0	0 0	0 0
128		1 1	0 9	0 1	1 0	0 0	0 0	0 0	0 0	0 0	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
129		1 1	1 1	1 1	1 1	1 1	1 9	0 0	0 0	0 9	9 1	9 1	1 9	1 1	9 1	9 1	9 9	9 9	9 9
130		1 1	1 1	9 1	1 1	1 1	0 1	0 0	0 0	0 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
131		1 1	9 9	1 1	0 9	9 9	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
132		1 1	1 1	1 1	1 1	0 1	9 9	0 0	0 0	9 0	1 1	1 1	9 1	1 1	1 9	1 9	9 9	9 9	0 0
133		1 1	1 1	1 0	1 1	1 1	9 0	0 0	0 0	0 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
134		1 1	1 1	9 9	1 9	1 1	9 9	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 9	1 1	1 1	1 1	0 1
135		9 9	1 9	1 9	1 9	9 1	9 9	9 0	9 0	0 9	1 1	9 1	1 9	1 0	9 1	1 1	0 9	0 0	9 0
136		9 9	1 1	9 9	0 9	9 0	0 0	0 0	0 0	0 9	9 9	1 0	0 0	1 0	1 1	9 0	9 0	0 0	0 0
137		9 0	9 1	9 1	9 9	0 0	9 9	9 0	9 0	0 9	9 1	9 1	1 9	1 1	9 1	0 0	0 0	0 0	9 0
138		9 1	1 1	9 1	9 9	0 0	9 9	9 0	9 0	0 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
139		1 1	9 1	9 9	1 9	9 0	9 9	9 0	9 0	0 9	9 1	9 9	1 9	9 9	9 9	9 0	9 0	9 9	9 9
140		9 1	1 1	9 1	9 9	1 1	9 9	9 0	9 9	0 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9

APPENDIX : (Continued)

Student No.		Pretest									Posttest								
	Skill	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
	Item	2 13	5 18	6 15	10 16	4 7	12 17	1 14	9 11	3 18	4 11	2 17	5 18	6 10	1 16	7 14	3 12	9 13	8 15
141		9 1	1 1	9 1	1 9	1 1	9 9	9 0	0 0	0 9	1 1	9 1	1 9	1 1	9 1	1 1	1 1	1 1	9 1
142		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	9 9	1 1	1 1	0 1
143		1 1	1 1	1 9	1 1	0 0	9 9	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0
144		1 1	1 1	1 1	1 9	9 9	9 9	0 0	0 0	0 9	1 1	1 1	1 9	1 1	1 1	1 1	1 1	1 1	0 1
145		9 0	0 0	9 0	0 9	0 0	9 0	9 0	0 0	0 9	1 1	9 1	9 9	1 9	9 0	9 9	9 0	9 0	9 9
146		9 0	1 1	9 0	1 9	1 1	9 9	9 0	9 0	0 9	9 1	9 1	1 9	9 1	9 1	9 1	9 9	9 9	9 0
147		1 1	1 9	9 1	1 9	1 1	9 0	0 0	0 0	0 9	1 1	9 1	1 9	0 0	9 1	0 0	0 1	0 0	9 0
148		1 1	1 1	1 1	1 1	9 1	9 9	9 0	0 9	9 9	1 1	1 1	1 1	9 9	1 1	1 1	1 1	1 9	9 9
149		1 1	1 1	9 1	1 9	1 1	9 0	0 0	0 0	0 9	1 1	9 1	1 9	1 1	9 1	1 1	1 1	1 1	9 1
150		9 1	9 9	1 1	9 9	9 1	9 0	9 0	0 0	0 9	1 0	1 1	1 0	0 1	1 1	1 0	0 0	1 0	0 0
151		0 1	0 9	0 0	1 1	0 9	9 0	0 0	0 0	9 0	1 1	1 1	1 1	1 1	1 1	1 1	1 0	1 1	0 1
152		1 1	0 9	1 1	0 9	1 9	9 0	0 0	0 0	0 0	9 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 0
153		1 1	1 1	1 1	1 1	0 1	0 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
154		1 1	1 1	1 9	1 1	1 1	1 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
155		1 1	1 9	1 1	1 1	1 1	1 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
156		1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	1 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
157		1 1	9 1	9 1	0 0	0 0	0 9	0 0	0 0	0 0	1 1	9 1	1 9	0 1	9 0	1 1	0 9	9 0	0 0
158		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0
159		1 1	1 1	1 1	1 1	0 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
160		1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
161		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	0 1	1 1	1 1	1 1	1 1	0 1
162		9 1	1 1	9 1	1 9	1 1	9 9	9 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 0	1 1	0 1
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164		1 1	1 1	1 1	1 9	1 1	9 9	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
165		1 1	1 1	1 1	1 9	9 0	9 9	0 0	0 0	0 9	1 1	1 1	1 1	1 0	1 1	1 1	1 1	1 1	0 0
166		9 1	1 1	9 1	1 9	1 1	9 9	9 0	9 0	0 9	1 1	9 1	1 9	9 1	1 1	1 1	1 1	1 1	1 1
167		1 1	1 1	1 1	1 0	1 1	0 9	0 0	0 0	0 9	9 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0
168		1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	9 0	0 0	0 0	0 0
169		1 1	1 1	9 1	1 9	1 0	9 0	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
170		1 1	1 1	1 1	1 9	1 1	9 0	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 0

APPENDIX : (Continued)

Student No.	Pretest Skill 1	Pretest Skill 2	Pretest Skill 3	Pretest Skill 4	Pretest Skill 5	Pretest Skill 6	Pretest Skill 7	Pretest Skill 8	Pretest Skill 9	Posttest Skill 1	Posttest Skill 2	Posttest Skill 3	Posttest Skill 4	Posttest Skill 5	Posttest Skill 6	Posttest Skill 7	Posttest Skill 8	Posttest Skill 9
Item	2 13	5 18	6 15	10 16	4 7	12 17	1 14	9 11	3 18	4 11	2 17	5 18	6 10	1 16	7 14	3 12	9 13	8 15
171	9 1	1 1	9 1	1 9	1 1	9 0	9 0	0 0	0 9	1 1	9 1	1 9	1 0	9 1	0 0	0 0	9 0	9 9
172	1 1	1 1	1 1	1 1	1 1	9 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1
173	1 1	9 1	1 1	1 9	1 1	9 9	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 1
174	1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 0
175	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0	0 0	1 1	1 1	1 1	1 1	0 0	1 1	0 0	0 0	0 0
176	9 9	9 9	9 0	9 9	0 0	9 9	9 0	9 9	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
177	9 1	1 1	9 1	1 9	1 1	9 1	9 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 1	0 9
178	1 1	1 1	1 1	1 9	1 1	9 1	0 0	0 0	0 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9	9 9
179	9 0	1 1	1 1	1 1	0 1	9 9	0 0	0 0	9 9	9 1	1 1	1 9	1 1	1 1	9 0	0 0	0 0	0 0
180	9 1	1 1	9 9	1 9	1 1	9 9	9 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	1 1	1 1	0 0
181	1 1	1 1	1 1	1 1	1 1	9 9	0 0	0 0	0 0	1 1	1 1	1 1	0 1	1 1	T 1	0 0	1 1	0 1
182	1 1	1 1	1 9	0 1	1 0	9 9	0 0	0 0	0 0	1 1	1 1	1 1	1 1	1 1	9 9	0 1	0 0	0 1
183	1 1	1 1	1 9	1 9	9 1	1 0	0 0	0 0	0 9	1 1	1 1	1 1	1 1	1 1	1 1	0 0	0 0	0 0
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