Abstract

SMITH, SHIRLEY MCCRAW. A Cross-Age Study of Students' Conceptual Understanding of Interdependency in Seed Dispersal, Pollination, and Food Chains Using a Constructivist Theoretical Framework. (Under the direction of Dr. Glenda S. Carter)

The purpose of this research was to investigate students' understanding of interdependency across grade levels. Interdependency concepts selected for this study included food chains, pollination, and seed dispersal. Children's everyday concepts and scientific concepts across grade levels represented the focus of conceptual understanding. The researcher interviewed a total of 24 students across grade levels, six students each from grades 3, 7, and 10, and 6 college students. Data were collected by means of interviews and card sorts. A constructivist theoretical framework formed the groundwork for presenting the focus of this study and for interpreting the results of the interview data. Results were analyzed on the basis of identifying student responses to interview questions as either everyday concepts or as scientific concepts, along with transition through the zone of proximal development (ZPD) by mediation, as developed by Vygotsky

Results revealed that children across grade levels vary in their everyday and scientific understanding of the three interdependency concepts. Results for seed dispersal showed little evidence of understanding for grade 3, that is, seed dispersal was not within the zone of proximal development (ZPD) for grade 3 students. Students in grades 7 and 10 showed a developing transition within the zone of proximal development from everyday to scientific understanding, and college students demonstrated scientific understanding of seed dispersal. For pollination and food chains, results showed that grades 3, 7, and 10 were in transition from everyday to scientific understanding, and all college students demonstrated

scientific understanding. The seed dispersal concept proved more complex than pollination and food chains.

The findings of this study have implications for classroom teachers. By understanding the dynamic nature of the ZPD continuum for students, teachers can plan instruction to meet the needs of each student.

A CROSS-AGE STUDY OF STUDENTS' CONCEPTUAL UNDERSTANDING OF INTERDEPENDENCY IN SEED DISPERSAL, POLLINATION, AND FOOD CHAINS USING A CONSTRUCTIVIST THEORETICAL FRAMEWORK

by

SHIRLEY MCCRAW SMITH

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APPROVED BY

Dr. John C. Park	Dr. James E. Mickle
Dr. Leigh Ann Haefner	Dr. Glenda S. Carter Chair of Advisory Committee

DEDICATION

This dissertation is dedicated

to those who teach and to those who seek to understand what is taught

by observing, thinking, doing, and assessing in order to know and to appreciate

scholarly endeavors and to become an independent learner.

Whatever is worth doing is best accomplished with an aim toward perfection.

BIOGRAPHY

Shirley McCraw Smith was born in scenic southwestern rural Virginia in Carroll County only a few miles from the Blue Ridge Parkway. The second daughter of Ruth Frances Dawson McCraw and Troy Lee McCraw, Shirl followed her parents' interest in plants. Her father walked his Sugarloaf mountain land every day, while her mother spent long hours as a homemaker and gardener. Shirl hikes the mountain land at every opportunity, looking for wild flowers and photographing the changing landscape. Her parents are now deceased, but she continues the interest in nature and walks on the old wagon trails and roads that preceded paved construction.

Shirl obtained her undergraduate degree from Appalachian State University with a Bachelor of Science degree in biology. She earned her Master of Arts in Teaching degree from Duke University, with an emphasis on education and biology. Her interest in Duke now centers on Duke basketball and the athletic department, which her family and friends enjoy as well. She took numerous classes at UNC-CH studying instructional design, leadership, and botany. Obtaining a doctor of philosophy degree in science education with a minor in botany has been a lifelong goal. She found North Carolina State University to be a student-oriented university during her doctoral studies.

Now that Shirl has completed the requirements for her doctoral degree, she has new interests. She plans to use her doctoral degree in teaching, writing, and consulting. She is leading the effort to convert the now closed elementary school that she attended into a community complex with a library, museum, botanical garden, and college classes. Because of all the time and effort settling her parents' estate, she is interested in law. An added interest is to open an antique, gift, and plant shop, which will be called Sugarloaf Antiques and Gifts. She will finally showcase her interest in art by doing some original art and graphic design works to sell. Certainly, she plans to teach biology and to continue researching, writing, and consulting on Vygotsky and constructivism. Her very next effort, however, is to take flying lessons and to continue to look for a Beechcraft Bonanza.

Acknowledgements

First of all, I thank my parents for providing me with the best childhood possible. My parents met on a bridge as they walked to church, and attending church was my mother's favorite activity. Attending church on Sunday makes the week complete and is a good start on a new week. My father liked church, but he much preferred to be walking and looking for nature's surprises. My parents, my two older brothers, and my sister spent as much time as possible with our extended family, neighbors, and friends. My family placed true value on nature and living on a small farm. Visiting relatives and talking about gardening and the farm animals brought interest and humor. Gardening was a necessity, and we had all kinds of fruit trees from which to share the bounty of this good earth.

I thank North Carolina State University for focusing on being student oriented. Faculty in the Department of Mathematics Science and Technology Education and in the Department of Biology helped me extensively in my entire program. Having completed my dissertation proposal except the research protocol, I was simply not sure how to prepare the questions. Dr. John C. Park offered invaluable assistance in helping me write the protocol for interviewing. Dr. James E. Mickle verified the accuracy of the biology information, and recommended a final data summary graph. Dr. Leigh Ann Haefner graciously agreed to serve on my committee on brief notice. Thanks especially to Dr. Glenda S. Carter for agreeing to chair my dissertation committee. She turned around corrections tremendously fast and efficiently and worked late evenings and weekends. I progressed, finally, with her encouragement and support and most importantly, her pleasantness and relentless passion for revisions during difficult times.

In reviewing my dissertation work, I must refer to one science educator whose work provided much of the framework for my research theory, Rosalind Driver, a professor whose professional career was spent mostly in England, but briefly in the United States. A tribute to Dr. Rosalind Driver by her colleagues (1997) focused on three attributes: vision, energy, and joy. Dr. Driver was said to have exercised vision in the pursuit of excellence worldwide, to see individually and corporately where science education research was heading. She saw the big picture, then tackled the details. Second, Dr. Driver exhibited energy with a capital E. Ros demonstrated proactive energy, a sense of urgency, the force and will power to act relentlessly toward her vision. She didn't procrastinate, for meetings took place, proposals were written, research was completed, and papers and books were published. Personal determination and courage helped her to tackle every obstacle in pursuit of her goals. She found great joy in those around her, and was generous with her time, fun, caring, supportive, and encouraging. She found diamonds among rocks, orchids among weeds, and shared the value, the joy, with all of us, especially through the fruits of her labor.

My dissertation also contains much theoretical framework based on Lev S. Vygotsky, a Russian whose work was done in the early 1900s, often during serious illness. Vygotsky concluded that children learn by integrating their everyday concepts with scientific concepts through their zone of proximal development, which is the difference between what a child can do alone and what can be accomplished through parents and teachers, or a competent peer. Vygotsky explained in detail how children learn concepts, and the mental tools involved, along with the importance of word meaning and language. Vygotsky, too, had a vision and worked relentlessly on his ideas, which the world now tries to envision. Through both Driver and Vygotsky, I now have a clearer view of students' understanding of phenomena of the natural world as learning evolves.

Just as in any endeavor, numerous people help in various ways. Completing the protocol questions demanded finding photographs. I had capable assistance with both photography and Internet location of the photographs used with the protocol, as well as help with the computer generation of much of the dissertation, especially charts and graphs. Computer and printer technical support was often needed and much appreciated. I thank my family, my friends, and all the people who have been truly patient with me. I now perceive the vision, the energy, and the sheer joy of accomplishment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

A change in the vision of scientific knowing and understanding evolved in the past years as a result of numerous reform standard publications. In 1989 in the United Kingdom, the National Curriculum Council commissioned a research group to document students' development of conceptual understandings across the 5-16 age range. Documentation of some research into physical science concepts had been done previously. To reform curriculum planning in all of science to achieve a balanced research perspective, researchers focused on documenting biological science conceptual progression as well (Driver, et. al., 1995). In America, the National Science Education Standards published by the National Research Council (1996) focused on generating across age standards in all the sciences. Along with standards, researchers focused on a change in how children learn more effectively, not through lecture, but through constructing their own way of thinking by a method known as constructivism.

Background

The historical background of constructivism progressed from the time of Vico to Piaget and Vygotsky, with numerous other researchers along the way. Little attention focused on really listening to students' answers or constructs until educators started analyzing responses to questions. Previously, what mattered was whether students were right or wrong in their responses. Gradually, educators started taking a close look at children's responses and analyzing their thinking. The introduction of concept maps presented a means of organizing and illustrating children's thinking. Answers to questions were no longer simply right or wrong with varying shades of meaning. Students' thinking could now be analyzed to understand how the tools of the mind functioned to generate responses.

A fundamental issue of studies involving students' conceptual progression in specific content areas relates to the specific data collected and to the data analysis (Leach, et. al., 1995). Progression in students' thinking changes across grade levels. Younger children tend to offer descriptions of natural phenomena rather than explanations. Although younger children tend to use what Vygotsky called everyday concepts, the tendency is to interweave the everyday concepts with scientific concepts with progression in development. For example, younger students would say an apple rots because it becomes brown and soft. Depending on the level of conceptual progression, an older student would use a causal explanation. For example, true, the structure of the apple changed during the rotting process, but why.

Both experience and social factors influence students' thinking about phenomena in the natural world. Students differ in their observations of the natural world. As a result, conceptual understanding varies. As young people develop, changing views occur as everyday and scientific concepts merge. Students build on their knowledge base from one year to the next. As a result, researchers involved with writing standards in concepts to be achieved across grade levels include increasingly complex topics to add to the knowledge base. This research focuses on the biological knowledge base, specifically topics relating to plants, for children's conceptual progression.

Conceptual understanding of ecological interdependency of life is an important topic included in reform standards (American Association for the Advancement of Science [AAAS], 1993; National Research Council [NRC], 1996). Students' understanding of the interdependency of plants and animals with the environment is a major area of emphasis in

K-12 and college science curriculum requirements. Interdependency is an interaction or interrelationship between or among plants and animals and the environment, a relationship that is necessary for survival. Interactions can be beneficial, harmful, or neutral to the organisms involved. Some types of interdependency include flowers and their pollinators, food chains, and seed dispersal, all of which were emphasized in this research study. The interdependencies were researched on the basis of students' everyday and scientific concepts.

Food chains and food webs, pollination, and seed dispersal are to be taught at specific grade levels (AAAS, 1993). Interdependencies of plants and animals, populations, ecosystems, food chains/food webs, and biological adaptations are all represented in the content standards in biological sciences for K-12 (NRC, 1996). Interactions or interrelationships between or among organisms, such as predation, symbiosis, mutualism, and parasitism, include the components of niche, habitat, population, community, ecosystem, biome, the patterns of energy flow (food chains/food webs) through an ecosystem, adaptations, and evolution (National Science Teachers Association, 1993). Energy flows through ecosystems in one direction, from photosynthetic organisms to herbivores, carnivores, and decomposers. In the process of energy flow, organisms cooperate and compete in ecosystems, forming interdependencies (National Science Teachers Association, 1995).

The purpose of this cross-age research study was to investigate children's everyday and scientific concepts of interdependency in pollination, food chains, and seed dispersal. One focus of this research study was to analyze the understandings students have about specific interdependencies between plants and animals. Students' understanding of the interrelationships among pollinators, seed dispersal, and food chains was explored.

Theoretical frameworks involved in the research were based on Jean Piaget, a Swiss constructivist, and Lev Vygotksy, a Russian researcher studying children's conceptual development. Cross-age data served to relate the development of students' conceptual understanding to the zone of proximal development (ZPD). The ZPD is an indication of the teacher's role in learning, as well as the impact of group learning, and a possible source of impact on curriculum design. The research was designed to collect and analyze data to find possible explanations to the following research questions for students' conceptual understanding.

Specifically, the research focused on finding answers to the following questions involving students' understanding of the concept of interdependency:

1. What everyday and scientific concepts do students have pertaining to biological interdependency of pollination, food chains, and seed dispersal?
2. What patterns of student knowledge of interdependency in pollination, food chains, and seed dispersal are evident across grade levels?
3. How can results from the interviews be used to construct an understanding of a student's zone of proximal development (ZPD) with respect to the interdependency concepts of pollination, food chains, and seed dispersal?

Significance of the Study

Interdependency influences the everyday experiences of children. No previously published research has pertained directly to students' understanding of pollination interdependency. Research involving food chains and seed dispersal has not involved everyday and scientific concepts. The importance of our understanding of students' conceptions of the interdependency of flowers and their pollinators, food chains, and seed dispersal is as follows:

1. The cross-age study design allowed comparison of the depth of understanding of the concept of pollination interdependency among grade levels 3, 7, 10, and college students.
2. The study gave insight into whether the students involved link pollination interdependency to food chains.
3. The research indicated whether students across grade levels relate pollination interdependency ultimately to seed dispersal.
4. The study analyzed the relationships among pollination, seed dispersal, and food chains.

<u>Rationale</u>

Research examining students' understanding of food chains and food webs shows distinct differences in children's knowledge of the concept of interdependency. On the other hand, a review of the literature pertaining to students' understanding of pollination and seed dispersal revealed that most reports were only descriptions of activities, thus indicating gaps in the research on children's understanding of these concepts. In the current cross-age study, students' everyday and scientific knowledge of food chains/webs, pollination, and seed dispersal will be explored. Cross-age studies are designed to trace the conceptual progression of children across age ranges. Previous research has not focused on differences between students' everyday and scientific knowledge of the three concepts reviewed here.

Wood-Robinson (1991) reviewed research studies on young people's concepts of plants. Research on students' understanding of plant topics has focused largely on plant nutrition. Conceptual understanding in the biological sciences, especially in reference to plants, represents a neglected area of study. More people tend to identify with animals than to observe plants. Throughout the history of science, classic experiments focused largely on physical science phenomena until now.

What is the importance of plant-animal interdependencies to survival? What are the interrelationships among pollination, food chains, and seed dispersal? What is the significance of pollination to plants? Pollination is interdependency between flowers and their pollinators whereby plants may be dependent on animals for transferring pollen, and the animals may benefit as well by acquiring food. Ultimately, the survival of some plant species may be dependent on certain pollinators. In fact, the interdependency of pollination may impact human survival and is therefore a critical area of students' understanding across grade levels. An analysis of students' conceptual progression from everyday concepts on a contextual basis, to scientific concepts on a non-contextual front offers insight into students' ways of thinking. How new knowledge builds on students' existing structure lends further insight into how children construct conceptual understanding. This study used a phenomenological approach involving students' reactions to photographs of biological concepts.

Chapter 2

A Review of the Literature

Part one of the literature review presents ideas on students' conceptual understanding and progression. The theories of Vygotsky and Piaget are presented in detail, along with related research articles. The second part of the literature review is based on the three plant or plant/animal interdependency concepts: food chains, pollination, and seed dispersal. Part three of the review of the literature delineates children's conceptual trajectories as researched through cross-age studies.

A review of K-12 science textbooks and college biology textbooks has included increasing information devoted to interdependency and specifically to pollination in the past few years. As the reform standards continue to delineate the areas of ecology important to each grade level, the information may be incorporated into the curriculum. Examining the influence of everyday school experiences on students' scientific understanding of interdependency is an important area in science education research (Driver, et. al., 1996; Gallegos, et. al., 1994; Griffiths & Grant, 1985; Leach, et. al., 1991, 1995, 1996a, 1996b). The current research study focused on the impact of everyday concepts learned culturally and socially on scientific concepts that are acquired through formal learning.

As children develop psychologically, concrete and formal reasoning evolve through the context of social interaction with parents, teachers, and competent peers. Elements of Piaget's constructivism and Vygotsky's socio-constructivist theory of scientific concept development will be combined to provide a theoretical framework for children's conceptual development for this study. The research focused on children’s construction of knowledge using everyday concepts or prior knowledge, which eventually evolves into scientific or true concepts. Everyday concepts represent the understanding of a concept that a child first brings to the classroom. Through formal learning mediated by educators, tutors, or peers, everyday concepts become scientific concepts.

According to Vygotsky, conceptual change is a continuous process in which the student collaborates with teachers, parents, and competent peers to transform everyday concepts into scientifically accepted concepts (Howe, 1996). Vygotsky linked everyday and scientific concepts through the zone of proximal development. The zone of proximal development (ZPD) is the difference between a child's actual level of development and the level of development possible through an adult or competent peer. Leontiev (1985) explained the relationship between scientific and everyday concepts as follows:

> The degree to which the child masters everyday concepts shows his actual level of development, and the degree to which he has acquired scientific concepts shows the zone of proximal development. (Leontiev, 1985, p. 47-48)

Vygotsky's zone of proximal development is the difference between the child's actual development alone and his or her potential development with guided assistance. Vygotsky's idea of the zone of proximal development serves to connect a general psychological view of child development with a pedagogical view of instruction. His underlying assumption of the concept is that development and instruction are socially originated, so to understand the two processes, one needs to analyze social relationships. By social relationships, Vygotsky meant interaction with family, friends, educators, and competent peers. Every person has a unique social relationship dependent on the environmental setting. According to Vygotsky, a child is limited in the capacity to copy actions that exceed his or her own capacities. However, a child can achieve more both independently and with understanding when in a social setting guided by adults. The difference between the level of accomplishment with adult guidance and the level of achievement independently is the zone of proximal development (Hedegaard, 1996, p. 172).

Shif, a student researcher working with Vygotsky, conducted a study based on factors distinguishing scientific concepts from everyday concepts in reference to the zone of proximal development. Everyday concepts evolve spontaneously according to the child's reflections on daily experiences occurring during social interactions. The experiential nature of everyday concepts leads toward classification as being unsystematic and contextual "complexes, " rather than actual concepts. In contrast, scientific concepts are true concepts that originate during formal instruction and are hierarchical, logical, and decontextualized structures. Vygotsky researched the interrelationship between everyday and scientific concepts and concluded that scientific concepts develop more quickly than everyday concepts. Scientific concepts aid structurally in the practical development of everyday concepts. To Vygotksy, the zone of proximal development (ZPD) correlated with the interaction between scientific and everyday concepts and the socialization of meaning between a child and an adult or more capable peer, which leads to formal learning (Kozulin, 1990). Carey (1985) viewed the relationship between everyday concepts versus scientific concepts as a problem of development of the child from novice to expert. In a detailed monograph, Carey linked her conclusion to Piagetian stage theory and philosophical theory change rather than attributing the idea to Vygotsky (Kozulin, 1990).

Vygotsky wrote that the central fact of his theory is mediation between the child and adult, especially on the nature of social interactions. The strength of scientific concepts lies in the child's capacity to use the concepts voluntarily (Vygotsky, 1987; Moll, 1990, p. 9). In contrast, the weakness of everyday concepts is a lack of systematic organization and the child's inability to manipulate them voluntarily. Vygotsky focused on the manipulation of language in the development of scientific concepts and as an important characteristic of formal schooling. Researchers have linked Vygotsky's everyday and scientific concepts to children's ideas and to students' understanding of concepts.

Plant Concepts

Children's biological ideas on ecology, inheritance, and evolution result from their construction of knowledge of the living world from firsthand experience, conversations with parents and teachers, reading, and watching media events (Wood-Robinson, 1995). How students progress in their explanation of pollination, food chains, food webs, seed dispersal, and adaptations compose the major part of the current study. A survey of the literature on children's understanding of interdependencies indicates increasing research pertaining specifically to plant concepts (Driver, et. al., 1996; Gallegos, et. al., 1994; Griffiths & Grant, 1985; Leach, et. al., 1991, 1995, 1996a, 1996b). The general consensus has been that limited research studies have involved children's concepts of botanical topics.

Children's understandings of food chains and food webs were the focus of three extensive and related studies on ecology (Leach et. al., 1995, 1996a, & 1996b). All three studies examined the conceptual progression of students' understanding in ecology across the 5-16 age range. The first study focused on theoretical background, design, and methodology (Leach, et. al., 1995). Children's progression in thinking about natural processes was described in terms of three interrelated factors. These three factors were students' knowledge of natural phenomena, students' ontological or developmental shifts in understanding the natural phenomena, and epistemological changes relating to how ideas were generalizable across a range of natural phenomena. For example, as children develop in age, their explanations progress from descriptive to causal (Leach, et. al., 1995). Both Piaget’s stage theory and Vygotsky’s pyramid of concept development tend to support conceptual progression in children’s construction of knowledge.

The second study of the three-part series involved children's ideas on the cycling of matter in ecosystems, specifically energy flow from producers to consumers (Leach, et. al., 1996a). Part three of the studies focused specifically on cross-age understanding of the interdependency of organisms (1996b). The main features of interdependency considered were composition of balanced communities, population size in communities, relationships between organisms composing food webs, and types of models students use to explain interdependency of organisms (Leach, et. al., 1996b).

Wood-Robinson (1991) reviewed literature pertaining to children's understanding of a number of plant concepts, including classification, plant structure, osmosis or water relations in plants, and plant nutrition or photosynthesis. In a subsequent research study on children's understanding of evolution, specifically adaptation and the inheritance of characteristics, Wood-Robinson (1994), emphasized the importance for teachers to ascertain prior beliefs of students before planning their teaching. Seed dispersal by wind as a dynamic ecological process, was the focus of another study pertaining to plant topics (Thomson & Neal, 1989). Students saw only the results of such processes; observing the occurrence of the actual ecological event of seed dispersal would make learning more exciting.

From an early age children begin to learn everyday concepts from their family and peers. Wellman and Gelman (1992) found evidence to indicated that children acquire naive foundational theories in at least three areas of scientific study, including biology, physics, and psychology. Their study indicated that children possess a domain-specific foundation or framework depending on interconnected reasoning and causal beliefs. Naive biology pertains to beliefs about certain causal mechanisms. The view of cognitive development cited by Wellman and Gelman as being domain-specific presents important questions for research (Flavell, 1992).

Research studies pertaining to children's understanding of concepts may have implications for planning and sequencing science curricula (Driver, Leach, Scott, & Wood-Robinson, 1994). If conceptual understanding is a curricular goal for science teachers, then planning instructional courses using research-based knowledge of children's conceptual development may prove beneficial. According to Driver, et. al, (1994), a central argument of their research was that

> If courses are to relate appropriately to learners, curriculum decisions may also need to take account of what is known about the processes of knowledge acquisition in science. Furthermore, it is suggested that cross-age research data on students' domain-specific reasoning in science, undertaken over the last two decades, provides an important base on which decisions about such developmentally organized curricula can be made. (p. 89)

Plant biology is a neglected topic of study and research at all levels in our schools and universities. The National Research Council (1992) stated that the central focus of the nation's teaching and research funding should be the biology of plant life. Children's understanding of photosynthesis has been well documented (Eisen & Stavy, 1988; Haslam & Treagust, 1987; Lazarowitz & Penso, 1992; Stavy, Eisen, & Yaakobi, 1987;Wandersee, 1983). However, research into children's understanding of other plant topics is limited.

Engel Clough and Wood-Robinson (1985) indicated that much of the research into children's conceptual understanding has involved physics. A reason cited for the neglect of biological topics was the popularity of investigations using Piagetian frameworks, which involve physical science concepts. Shayer (1974) contended that biological concepts are non-hierarchical and less distinct than physical science concepts. Being less discrete, biological concepts tend to interweave with related concepts and are more difficult to analyze.

At least one research study pertained to the connection between understanding physical and biological concepts. Driver and Erickson (1983) framed the over-all structure of their study on the review of research pertaining to students' conceptual frameworks on the basis of the premises researchers use to justify their programs. Three empirical premises, a value premise, and a conclusion justify their study:

Empirical Premise 1: Many students have constructed frameworks from their physical and linguistic experiences, which they can use to interpret natural phenomena studied formally in school.

Empirical Premise 2: Students often become confused as their conceptual frameworks lead to different predictions and explanations from those learned in school.

Empirical Premise 3: Instructional planning based on teaching strategies, which consider student conceptual frameworks will lead toward the development of frameworks that parallel school science concepts.

Value Premise 1: The goal of research should be to design studies, which will lead students to an improved understanding of school science.

Conclusion: Researchers should engage in research which:

a. Reveals conceptual frameworks students bring to the classroom,

b. Investigates how students interact with instruction, and

c. Use the resulting knowledge to develop instructional programs.

A review of the literature indicates that progress is being made in research on students' understanding of conceptual frameworks in botany, the study of plant life. The over-all goal of conceptual research, then, should be to investigate students' thinking, not as a container to be filled with facts, but as a structure which functions to correlate students' everyday concepts with scientific concepts in order to understand their ecological interdependence with the environment. Thorough understanding of concepts should include recognizing those concepts when used in a different context.

Leach et. al. (1995) explained the theoretical background, design, and methodology of their research into children's ideas on ecology. Progression in children's understanding is associated with changes in their ontology, that is, changes in their basic assumption about the nature of the world. Epistemological changes occur also and can be detected while reviewing the nature of children's explanations across ages. Younger children tend to provide descriptions rather than explanations, whereas older children are more apt to explain using a causal point of view. For example, when asked why an apple rots, the young child might simply state that it rots because it is brown and soft. On the other hand, the older child is more likely to state that an apple rots because bacteria decompose it. The explanations of the responses of the younger and the older child represent the difference between everyday and scientific concepts as based on Vygotsky, and developmental age as based on Piaget.

Another issue for consideration of children's conceptual progression concerns the factors that impact the development of children's thinking. Leach, et. al. (1995) proposed that social factors, especially language and everyday experiences, influence children's ways of thinking and talking about the nature of certain scientific phenomena. Solomon (1987) referred to the everyday ways of knowing as 'life world knowledge,' actually the knowledge that both children and adults alike tend to take for granted. Everyday knowledge often represents viewpoints that have become a part of our common culture, and may or may not coincide with the scientific way of knowing. An example of an everyday way of knowing is the idea that plants bend toward sunlight because they need light. The scientific view is that the plant bends toward the light because the plant growth hormone auxin causes the cells to grow faster on the side away from the light, therefore causing the plant to bend toward the light. Thus, once a student's everyday conceptual framework is clarified by scientific conceptual understanding, the student then has a true idea of the meaning of the concept involved.

Children's experiences with natural phenomena also influence their thinking (Leach, et. al, 1995). From a young age, children observe birds eating insects, butterflies, birds, and insects frequenting flowers, cockleburs or beggar's lice on their socks, and pollen on the ground. Observations impact students' thinking about the nature of scientific phenomena. Children seek answers to questions about observations from adults. The important point is that researchers need to recognize that children's experiences are always mediated by the current social representations. As a result, influences due to social factors and experience are difficult to dismantle and reorient scientifically. As Leach, et. al. (1995) summarized,

> Suffice it to say that when children are introduced, in school or elsewhere, to the science view of the concepts and phenomena which are of interest in this study, they start with an established personal history of listening, talking, experiencing and thinking about the matters under consideration. In this respect, progression in learning might be conceptualized as a dynamic and ongoing process involving additions, developments and changes to existing modes of thinking. Progression might be prompted by schooling or through more informal situations. In some instances children will integrate the science concepts learned in school with existing knowledge structures. In other cases, science knowledge will build on existing structures but will tend to be held separately from everyday ways of knowing and will be drawn as particular contexts demand. (pp.722-723)

Interdependency

The concept of interdependency pertains to interrelationships between plants and animals. Examples of interdependency include food chains and food webs, pollination, and seed dispersal. Living organisms are interdependent ultimately due to food supply (Ford & Smith, 1994). Whereas food chains and food webs have been extensively researched, virtually no research exists on students' understanding of pollination and seed dispersal. The purpose of the current literature review is to relate research involving students' understanding of food chains and food webs, pollination, and seed dispersal.

The first concept included in this study is the ecological food chain and food web continuum. A food chain is a series of successive feeding relationships beginning with a producer and followed by primary, secondary, tertiary, and perhaps quaternary consumers. A food web is a complex of interwoven food chains. Research into children's understanding of models of food chains and food webs is fairly comprehensive. For example, Alexander (1982) reported that the principles of ecosystems are most effectively taught through the analysis of food web relationships. A survey of secondary science teachers in the United States indicated that food chains and food webs were among the concepts important for students to know (Finley, Stewart & Yarroch, 1982). Although most teachers in the survey considered the two concepts easily comprehended by students, an analysis of the literature on food chains and food webs indicates that research data fails to substantiate the teachers' views. A number of research studies concluded that students have some level of difficulty understanding the concepts of food chains and food webs: (Adeniyi, 1985; Barman & Mayer, 1994; Gallegos, et. al., 1994; Griffiths & Grant, 1985; Johnstone & Mahmoud, 1980; Leach, et. al. 1995, 1996a 1996b; Webb & Bolt, 1990). Further discussion of these studies reveals the varying levels of understanding.

Leach, et. al. (1995, 1996a, 1996b) conducted three research studies into children's understanding of ecology relating to the cycling of plant matter and interdependency. Each of the studies involved the conceptual progression of understanding of approximately 200 children, aged 5-16. A series of written tasks and individual interviews using a variety of contexts, referred to as probes, were used to generate the data. Leach, et. al. (1996a) related children's ideas about the cycling of matter between organisms and between organisms and the abiotic environment. The authors focused on five main features of the cycling of matter: the source of matter for plant growth, plant growth requirements, the sources of matter for animal growth, the decay process, and the role of decay in the cycling of matter. Models of the cycling of matter and the flow of energy within ecosystems included producers making food by photosynthesis, which cycled and recycled through abiotic and biotic components of ecosystems. The models were designed to show a summary of ideas students should acquire by age 16. An analysis of the nature of children's explanations indicated disagreement with scientifically accepted concepts. By age 16 only a small number of students provided explanations of the cycling of matter consistent with the areas of photosynthesis, respiration, and decay. Leach et. al. confirmed their earlier conclusion (1991) that the reason for the limited understanding by students could be due to teaching the processes in isolation rather than as related concepts.

Leach et. al. (1996b) reported children's ideas about the interdependency of organisms in ecosystems. Examples of interdependency included composition of a balanced community, relative population size in communities, relationships between organisms composing food webs, and forms of interdependence, that is, how students view organisms as interdependent. An analysis of the results showed a range of children's ideas across ages. Results of the study indicated that many students, especially between the ages of 5 and 11, form a singular point of view, that is, a relationship between one predator and one prey organism, as in a food chain, rather that between populations, as in a food web. The authors reviewed a number of forms of interdependence in explaining students' conceptions on interdependence using teleological and anthropomorphic points of view. Students aged nine and above offer a range of explanations about relationships between organisms. By age 16 a small number of students provided explanations relating to competition between organisms.

Griffiths and Grant (1985) focused on the development and validation of a learning hierarchy model and the use of the model as a tool for identification of misconceptions in high school students' understanding of the concept of food webs. The model was used to ascertain students' responses as to how a change in one population of a food web would impact a second population on a different food chain within the food web. Research data reported on 200 tenth grade biology students indicated that almost the entire sample (95.5%) made common mistakes in identification of population shifts in one population impacting other populations along food chains within a food web. In questions pertaining to predator-prey effects on population changes, students showed varying levels of understanding.

Webb and Bolt (1990) reported that the predator-prey relationship characteristic of food chains is the principal component in students' understanding of food chain construction. The study included 108 secondary students and fifty-four first year university zoology students. Among the secondary students, fifty percent were 15 years old and fifty percent were 17 years old. Almost the entire sample of students at all levels had difficulty predicting outcomes when a change in one population of a food chain occurred within a food web. The authors concluded that ecological concepts must be developed at an earlier age or alternative frameworks may persist at the university level.

In their study of food chain construction by 9 and 10 year-old children in Mexico, Gallegos et. al. (1994) focused on children's preconceptions (prior everyday knowledge) and their understanding of predator-prey relationships. The research sample consisted of 506 children in grades 4 through 6. Conclusions were based on a single application of a three-task instrument. The instrument was administered following a classroom lecture/discussion in a fourth grade classroom. Teachers considered the concept of food chains to be a known topic among fifth and sixth grade children and wanted to check to verify the level of understanding. Children's preconceptions of size and ferocity of herbivores and carnivores were shown to guide their selection of predator-prey relationships in the construction of food chains. Food chains were constructed on the basis of predator and prey pairs, with the more ferocious carnivore selected to consume the weaker herbivore. Results indicated that students had not developed an understanding of the concept of producer as the basic link in food chains and food webs. The authors recommended that food chains be taught, not by isolation of predator-prey relationships, but from the context of ecological flow of solar energy transformed by the producer into chemical compounds and subsequently cycled through different trophic levels of consumers.

Another study pertaining to food chains and food webs focused on why the populations of organisms within the food chain or food web vary. Adeniyi (1985) identified ecological misconceptions held by secondary science students (N=232)
aged 13-15. Many of the students argued that herbivores were more numerous than carnivores within a community because people tend to keep and breed herbivores, such as cows and sheep, or that herbivores tend to produce larger numbers of offspring. In addition, many students viewed large populations on the basis of satisfying the food requirements of predators. For example, one student thought there would be a large number of insects because most of the consumers within a food web would rely on them for food.

Johnstone and Mahmoud (1980) devised a technique to isolate topics perceived difficult by high school and university students, teachers, examiners, and lecturers. All sources generally agreed on the topics causing the most difficulty, including energy requirements. The conclusion was that for topics perceived difficult by students and teachers, curriculum planners and researchers probably should focus on students' views of difficulty rather than relying on their own perceptions.

In their study of students' conceptual understanding of food chains and food webs, Barman and Mayer (1994) interviewed thirty-two students and surveyed eleven high school biology textbooks. The interview instrument included a card sort, a diagram, and interview questions. The card sort consisted of three cards with the names of a producer, an herbivore, and a carnivore. The student was asked to arrange the cards to show a food chain. Two hypothetical questions pertaining to a diagram of a food web were used to probe students' understanding of a food web. Interviews were audiotape recorded. Analysis of the research data indicated that most students gave basic, unsophisticated descriptions of the concepts of food chains and food webs. In addition, most of the students could identify several food chains in the food web diagram, but they did not understand the feeding relationships in a food chain and food web as a method of energy transfer among organisms. Furthermore, the majority of the students could not adequately explain the consequences of a doubling of the herbivore population or a major reduction in the carnivore population on other populations within the food web. An analysis of textbooks used in the classrooms indicated that at least half excluded sufficient information for students' understanding of energy transfer among organisms. The authors concluded the necessity of identifying ways to access the knowledge children already have and that basic concepts should not be overlooked simply because teachers think of them as being obvious to students.

Brumby (1982) focused on four problems to determine students' perceptions of the concept of life. Both a written assessment and an interview protocol were used. The "Web Problem" consisted of a diagram of a cobweb (spider web) and stated:

> You sometimes hear people using phrases like: "All of life depends on green plants," or they may speak of "a web of life." What do you think people actually mean when they use these phrases?' [Here is a diagram of a cobweb if it helps you to explain by drawing on it.] (Brumby, 1982, p. 615).

Approximately fifty percent of the fifty-two university-age students in the study interpreted the two quotes in terms of food chains. Only nine students mentioned photosynthesis, or conversion of solar energy, for the critical importance of green plants in a food chain. Most students indicated that plants exist for the benefit of higher organisms, especially man. Apparently, after studying secondary biology, the students had not yet integrated their concepts of photosynthesis, food chains, and nutrition to project an understanding of ecological energy flow in the biosphere. Brumby concluded that students memorize the characteristics of living things in a school setting and do not reason or apply their scientific knowledge through the context of the real world.

A review of children's conceptual understanding of forests and their inhabitants (Strommen, 1995) serves as a background into analyzing young children's thinking about science. Forty-one first grade children were asked to draw forests and then were interviewed about the type of life in forests, including producers and consumers. Little indication of understanding of the concept of food chains and food webs was evident; animals were generally assigned a single food. For example, bees were said to eat honey, and ants were equated with consuming sugar. Perhaps a more direct probe of food chains and webs would clarify evidence of understanding. Children generally equated most forest dwellers with the forest, but they tended to assign all animal types to the forest as well, including sharks, whales, and ducks, with no distinction, in the case of water dwellers, between fresh-water or marine life. Plant life, insects, and water relations were typically ignored. Children who lived near museums and zoos were more knowledgeable about forests. Perhaps due to the nature of portrayal in children's stories and fairy tales, the forest is viewed very concretely in terms of a general, non-human setting for animal habitats. Such knowledge can serve as a base to develop a curriculum to promote children's cognitive growth toward understanding more complex forest animal relationships.

Pollination is the least researched of the three selected concepts pertaining to interdependency. No research into students' understanding of pollination is available, but a number of activities and summaries can be found. In an article on pollination and flower structure, Macdonald (1990) stated that textbook authors are responsible for much incorrect information as a result of focusing on the structure of a typical flower. A typical flower may not represent the various adaptations for different pollinators. Scharmann (1991) included a concept map of angiosperm reproduction in his article pertaining to using the learning cycle to teach angiosperm reproduction. He did not include the term pollinates on the concept map, but instead indicated that pollen "lands on" the stigma. Pollination precedes fertilization and the two processes, often confused, are basic to understanding angiosperm reproduction.

The advent of biotechnology has resulted in numerous protocols for botanical research using fast plants, rapidly cycling *Brassica campestris* (*rapa*) L. Brassicas are widely available for students' use in understanding of botanical and biotechnology concepts, including pollination. Hafner (1990) discussed co-evolution of the symbiotic relationship between the Brassica flower and the honeybee. A detailed explanation of the pollination process accompanied the discussion of a pollination activity using the fast plants. Tomkins and Williams (1990) also reviewed the features and laboratory uses of fast plants. Fast plant cultivars have a five-week seed-to-seed cycle, and all have bee-pollinated flowers. The authors elaborated on the pollination features of fast plants and their bee pollinators and concluded that "there is some exciting teaching possible in this area" (p. 246).

Foote (1990) presented a comprehensive survey of flowers and their pollinators. Each type of pollination, including both floral and pollinator structures was discussed. A suggested activity based on observation during a field trip to a botanical garden or meadow explained how to record observations. Finally, field trip activities were described, including generating hypotheses as to the type of pollinator depending on the type of floral structure.

Clay-Poole and Slesnick (1983) discussed the biology of pollen and its many types in their article on pollen. They explained the adaptive value of cross-pollination strategies, as reflected in pollen structure. Included as well is an explanation of classroom studies involving the collection, photography, and identification of pollen. Detailed instructions explain how to germinate pollen.

According to Aston (1987), plant-pollinator interactions provide numerous possibilities for valuable contributions for studies at all levels, thus “a rich area for study” (Aston, p. 257). Several experimental activities are included. For example, in observations of plants while being visited by pollinators, why do pollinators reject certain flowers? Are there similarities in rejected flowers? How do bees recognize inferior flowers? All of these questions can be answered basically upon observation and microscopic examination of the rejected flowers.

Seed dispersal is another concept involving children's understanding of ecological interdependency. Several activities pertaining to seed dispersal can be found in the literature, but no research into students' understanding of the concept is available. Postiglione (1993) designed an activity on seed dispersal using Velcro, cockleburs, and wool. A protocol for the activity was described and several questions requiring an inquiry response were included.

Thomson and Neal (1989) developed an interesting and well-observed activity on wind dispersal of tree seeds and fruits. The main focus is on diaspores, the general term for dispersal units of trees, such as fruits, seeds or other structures. Each type of diaspore is categorized according to its characteristic aerodynamic behavior, such as rolling, tumbling, or floating. Two exercises are included. One focuses on the determination of the rate of fall of the diaspore in still air, and the second involves the measurement of displacement distances from the point of release. Inquiry-oriented questions center on design considerations in adaptation of seed dispersal methods, as well as on adaptive design of seeds, such as a particular germination location.

Bebbington & Bebbington (1993) developed a field activity on seed dispersal. The activity was designed to generate answers as to why plants produce seeds, what happens if all the seeds stay in the same place, and how the seeds are dispersed. Nichols (1986) designed an activity pertaining to gene flow and the measurement of dispersal distances in natural plant populations. Since plants are non-motile, then they are dependent on passive transport of pollen and seeds for survival.

<u>Cross-Age Studies</u>

A survey of cross-age studies pertaining to students' understanding of science concepts, including ecological interdependency of food chains and the cycling of matter, indicates that such studies have implications for curriculum planning (Driver, et. al., 1994). That is, cross-age studies provide research data to support what should be considered in the science curriculum. Cross-age studies provide a means for researching students' understanding of concepts. Conducting a cross-age study involves using the same instrument across grade levels, for example, grades 3, 7, 10, and college freshmen during the same time period. Such studies indicate children's understanding within a particular concept or domain, and report variations and similarities at different age levels. On the other hand, a longitudinal study is conducted over several years using the same student population. A review of some cross-age studies provides useful information for curriculum planning. As discussed previously, Leach, et. al. (1995, 1996a, & 1996 b) reported a series of three extensive cross-age studies of children's ecological ideas.

Driver, et. al. (1994) conducted a comprehensive review of cross-age studies for the purpose of curriculum planning. The authors indicated that in cases in which conceptual understanding is a curriculum goal, then how understanding of concepts evolves might be beneficial to instructional courses. A cross-age study as a method aids research into students' conceptual learning.

Engel Clough and Wood-Robinson (1985) conducted an interview study of 84 students aged 12 to 16 years to document their understanding of biological adaptation. The study represents a shift in emphasis on research into children's understanding of scientific concepts from Piagetian stage theory to a focus on the nature of ideas and beliefs children have on scientific phenomena based on everyday experiences. The authors concluded that little progress was made on children's understanding of evolutionary adaptation from 12 to 14 years, but by age 16, students showed noticeable improvement, although a number of alternative frameworks persisted. Their recommendation is that students need to be provided with more opportunities to explore alternative viewpoints through small group and class discussions.

Theoretical Framework

Many science education researchers see a connection between learning theory and educational practice (Rowell, 1984). Numerous learning theories abound, and various researchers cite their preferences. Murray (1979) stated that relating psychological theory to educational practice is a means of compatibility, not logic. Differing viewpoints on theories arise because psychological theories lack precision in how they are stated (Murray, 1979). Murray believed that a theory provides a heuristic role and serves to predict possible educational outcomes.

Rowell (1984) asked two questions as to whether overlaps occur between theories:

1. How specific are theories as they relate to educational strategies?

2. Can the same theory pertain to more than one strategy and be consistent?

Rowell looked to Toulmin's map, called theory analogy (Toulmin, 1972) for answers to his question. Toulmin argued that basic learning theories differ from those applied to education in much the same way as maps differ from itineraries. He explained that a good map is route-neutral. An itinerary, on the other hand, specifically pertains to particular routes. Furthermore, some educational theories are more similar to itineraries, whereas others are more like maps (Rowell, 1984).

In order to understand how students learn, teachers need to base their teaching on a theory of knowledge. Active education emphasizes the teacher as a facilitator of knowledge, not as one who imparts knowledge. The natural progression, then, is that a solid scientific foundation of education is needed, which bases teaching on genetic psychology and genetic epistemology (Jacobs, 1984). Rousseau stated, “Begin by studying your pupils, for assuredly you do not know them at all." A theoretical framework is a basis for teaching and learning, or simply knowing.

For the purposes of this study, the theoretical framework of constructivism was used, focusing on the learning theories of both Piaget and Vygotsky. Piaget's idea of constructivism involves conceptual development over time. His developmental theory focuses on the expectation that younger children tend to make egocentric observations, followed by more abstract observations as they develop. On the other hand, according to Vygotsky, the blending of children's everyday school experiences and theoretical concepts ultimately develops their understanding. Thus, interventions that occur during children's development vary by their experiences. For example, some students may have had some experience with gardens, whereas other students will have had very little, if any, experience with gardens. Depending on their development, everyday experiences, and social interventions, children tend to construct their own concepts over time.

Constructivism

The theoretical framework for this research is based on constructs of knowledge, that is, how children construct knowledge from the world around them. Knowledge and understanding of knowledge are constructed as individuals engage socially in group problem solving tasks (Driver, et. al., 1994). Several construct models have been developed. For the purposes of this study, no distinction will be made among theories labeled constructive, constructivist, or constructivism, for each has as a base, the root word, *construct*, therefore implying construct architecture. Construct architecture refers to how the theory is viewed in terms of construction of knowledge. In reality, most studies tend to use construct terms interchangeably, although basic differences are revealed when studied closely. A *construct* is a concept synthesized (constructed) by systematically arranging previous mental models, following instruction, into scientifically accepted conceptual models (Glynn & Duit, 1995). Constructs are personal tools, which are part of an organized system and which vary according to the range of convenience and contrast linked to a person's identity (Fetherston, 1997). The general conclusion is that the theory of constructivism as applied to science teaching and learning may be under theorized (Fetherston, 1997).

The term constructivism is used loosely without clear definition and without being specifically linked to an epistemological base. In addition, no clear accounts link constructivism as Piagetian in origin, radical in origin, as in von Glasersfeld (1989), or simply construction of objective reality. Vygotskian constructivism may provide an alternative to other construct theories (Fetherston, 1997). Cognitive psychologists define constructive, constructivist, or constructivism as learning in which students construct their own sense making or conceptual models by drawing from previous experiences and new information. Piaget (1970), Vygotsky (1962, 1978, &1987), and von Glasersfeld (1989) are among numerous epistemologists who have done research in developing construct-type theories using a social dimension to explain how students learn.

Constructivists are, first of all, interested in students' acquisition, understanding, and application of broad-based conceptual knowledge, such as photosynthesis, Newtonian mechanics, or atomic theory. In making sense of the world around them, students internalize relevant conceptual information and draw from everyday and scientific knowledge to construct personal understanding of the concepts being presented. Second, constructivists are "interested in the well-established idea that the learner's prior knowledge is a *sine qua non* in constructing meaning; that the interaction between new knowledge and existing relevant (private, personal) knowledge is the most important ingredient in the process of meaningful learning" (Pines &West, 1986, p. 584).

Fetherston (1997) has proposed a personal construct psychology (PCP) based on Kelly (1955) following a construct approach similar to Driver and Bell (1985), and consisting of seven categories:

1. The direction of learning is determined by the learner's existing constructs.
2. Learning involves the elaboration of a construct system.
3. Learning, questioning, and exploring occur continuously and actively.
4. Events can be interpreted in a large number of equally valid and equally possible ways.
5. Learning involves change in a person's construct system.
6. Construing is a refining process leading to abstraction and generalization.
7. Learning in science involves construing the construction processes of scientists, teachers, and students (sociality corollary).

   (Fetherston, 1997, pp. 805-807).

Fetherston's purpose in the PCP approach is to bridge the distinction between personal knowledge and formal scientific knowledge, which could be stated as the bridge between everyday knowledge as opposed to scientific knowledge.

The purpose of learning is to generate meaning, which leads to better prediction and control. Students and teachers alike are construing persons who construct their own meaning while learning science. Driver and Erickson (1984) stressed that teachers recognize the alternative frameworks students have pertaining to science. A study on student perceptions of social constructivist teaching indicated that a clearer understanding of group interactions would assist in developing social construction of knowledge into a more powerful learning approach (Hand, et. al., 1997). Lumpe and Staver (1995) concluded that cognitive group roles enhance the development of concepts during peer interaction.

Some recent research studies have focused on children's understanding of content-specific science domains (Johnson & Gott, 1996; Pfundt & Duit, 1994). The rationale for such research was that children's ideas play an important role in the teaching-learning process. "What a child is 'already thinking,' it has been argued, has a crucial bearing on how she or he might interact with teaching, and, therefore, has a determining role in any subsequent learning" (Johnson & Gott, 1996, p. 561). Such thinking reflects the widespread influence of constructivists.

Glynn and Duit (1995) described a construct theory. According to their constructive theory (constructive is their term of choice as opposed to constructivism, which they indicate cannot be a theory of learning):

> The construction of valid conceptual models is the hallmark of students' science achievement. When students construct conceptual models, they are making sense of their experiences--they are constructing meaning. Scientifically literate students are those who can construct and apply valid conceptual models of the world around them. (p. 4)

Because students differ as to the nature of individual experiences, they bring to the classroom varying personal mental models. Therefore, individual personal mental models correspond in varying degrees to scientifically valid conceptual models (Glynn & Duit, 1995). As a result, a distinction must be made between conceptual models and mental models (Glynn &

Duit, 1995; Norman, 1983). Conceptual models can be thought of as tools adapted for the understanding of physical or biological systems. Mental models represent the ideas students "have in their heads" (Norman, 1983, p.7) as a result of individual experiences and what guides the use of ideas gained from association. "Mental models are central to human thought processes" (Roth, 1995, p. 65). When asked to solve a problem or complete some task, students construct a mental model. For example, students construct their idea of a rectangle, a pollinator, a specific food chain, or a seed dispersed by the wind. Teaching serves to establish a direct relationship between students' personal mental models and scientifically valid conceptual models, that is, to unify the two models into a coherent conceptual understanding.

Students' mental models are usually learned in a variety of contexts, such as in their homes and in various community settings. Conceptual models, on the other hand, are usually learned in school, thus forming situational contexts, which depend on the situation in which learned (Glynn & Duit, 1995). Mental models are not forgotten because they continue to be reinforced according to the situation. Mental models and conceptual models may coexist within the students' long-term memories and be activated according to the situation at hand. Realistically, then, the goal of science instruction is to "activate the appropriate model in the appropriate context "(Glynn & Duit, 1995, p.20).

In their constructive view of learning science, Glynn and Duit (1995, p. 5) listed five conditions for learning science meaningfully:

1. Activate existing knowledge or existing mental models.
2. Relate existing knowledge to educational experiences.
3. Develop intrinsic motivation.

4. Construct new knowledge in the form of conceptual models.

5. Apply, evaluate, and revise new knowledge in authentic environments.

Before formal schooling, students have already experienced phenomena of the natural world. For example, students have mental models of heat versus temperature, pollination versus fertilization, food chain versus food web, and methods by which seeds are scattered and why. Children have constructed mental models of the world around them, which explain the occurrence of night and day, the seasons, and how green plants make food. Science teaching involves the use of science process skills, which refine scientific knowledge by helping students in a variety of scientific tasks. Teaching in an authentic learning environment serves to engage students in real-world applications to apply, evaluate, and revise knowledge (Glynn & Duit, 1995). Thus, mental models become conceptual models communicated through language and speech in the process of social interaction with others, most notably teachers and classmates.

Everyday problem-solving changes with the situation, thus known as situated, or contextual cognition. An authentic learning environment corresponds to an apprenticeship in which the learner models the master, a situation type setting in which "learning is squarely located in the process of social co-participation. Situated learning emphasizes learning through the engagement in authentic activities" (Roth, 1995, p. 29). *Authentic* means that the actual environment resembles a work-place setting where members engage in a particular activity. For example, in authentic science learning situations, students would be engaged in learning science as scientists. Roth (1995, p. 29) stated five qualities of authentic science classrooms which allow students to work in the way scientists work. Such classrooms would allow students to:

1. Learn in contexts constituted in part by ill-defined problems.
2. Experience uncertainties, ambiguities, and the social nature of scientific work and knowledge.
3. Engage in learning (curriculum), which is predicated on, and driven by their current knowledge state.
4. Experience themselves as part of communities of inquiry, in which knowledge, practices, resources, and discourse are shared.
5. Participate in classroom communities, in which they can draw on the expertise of more knowledgeable others, whether those others are peers or advisors.

Science in the workplace is comprehensive. Scientists must find sources of funding, and they often have to modify equipment to use for purposes not intended. Authentic classrooms would provide students with similar problems.

Contemporary perspectives on science education postulate that knowledge cannot be transmitted, but must be constructed through the learner's own mental capacity (Driver, et. al., 1994). By presenting an account of Galileo's intellectual explanation of free-fall motion as a challenge to interpret and explain scientific phenomena, Driver, et. al. (1994, p. 6) concluded that "once such knowledge has been constructed and agreed upon within the scientific community, it becomes a part of the . . . way of seeing things within that community." The cultural and social institutions of science serve to construct and communicate scientific knowledge. Scientific knowledge viewed as socially constructed and validated has important implications for science education--that learning science means being initiated into scientific ways of knowing and making meaning from these ideas on the individual level (Driver, et. al., 1994). Thus, the goal of science education is to mediate scientific knowledge to enable students to make sense of the natural world.

History of Construct Ideas

According to Hawkins (1994), constructivism as a general philosophy of learning has a long history. The first known construct-type theory, constructivism, was proposed nearly three centuries ago in 1710 by the Italian philosopher Giambattista Vico (von Glasersfeld, 1989). One of Vico's most basic ideas was that learners know nothing except cognitive structures synthesized using their own mental functions. To know is to construct. Vico further emphasized that to know, one must be able to explain in a way that others can understand. If the history of construct theory began with Vico, and has been taken up by others, such as Herbart along the way (DeBoer, 1991), then Piaget is largely accredited with lending credibility to construct theory through his voluminous writings on constructivism. Although some major theorists including Piaget were constructivist, the beginning of the constructivist movement in science education began with the article by Driver and Easley (1978) according to Johnson & Gott (1996). Much recent research pertaining to construct theory is interwoven with Piaget and the social aspects of constructivism as based on the learning theory of Vygotsky.

Through his research, much done in collaboration with Barbel Inhelder, and through his prolific writing, Jean Piaget proposed a theory of cognitive development consistent with constructivism. As Miller (1993) contended, Piaget's cognitive theory of genetic epistemology is best understood initially when presented as an overview followed by a more specific exploration. Piaget was by profession a biologist who became interested in developmental psychology, in essence a genetic epistemologist. Epistemology is the philosophy of knowledge. The term *genetic* implies "development." Piaget reasoned that by assessing the developmental changes that occur during the process of knowing and organizing knowledge, he could discover answers to questions pertaining to epistemology. He was intrigued by the philosophical concepts of thought, including space, quantity, time, and causality, so he developed empirical hypotheses to test these concepts (Miller, 1993).

Piaget claimed that knowledge is a process of mental activity, which reconstructs the external world (Jacobs, 1984). The learner actively constructs knowledge by acting either physically or mentally on an object. Cognitive development occurs as one's knowledge of the world undergoes changes. Organisms adapt physically to their environment according to their biological structure, and mentally according to their psychological level. Just as the embryo differentiates physically over time, Piaget reasoned that organisms also develop cognitively through adaptation over time (Miller, 1993; Piaget, 1970). He asserted that the basic principles of cognitive development parallel those of biological development (Piaget, 1952). He used the biological concepts of adaptation, organization, structure, equilibration, assimilation and accommodation as analogies of intellectual function. He defined intelligence, in a general context, as adaptation to the environment.

Piaget's theory is cognitive, involving central neural organizing processes and is concerned primarily with structure instead of content, focusing on how the mind works to understand concepts (Phillips, 1981). Piaget seldom used the term *learning* in his writings; instead, he refers to *development*, perhaps because of his being a biologist prior to becoming a cognitive psychologist. An organism inherits a genetic program that enables adaptation to its environment according to the stage of development. Intelligence, in this context, now becomes the ability to make adaptive choices (Phillips, 1981, p. 11).

Piaget's developmental theory is now considered "constructivist." Only later in life did he consider himself a constructivist, although the viewpoint that the cognizing subject constructs knowledge was central to his theory. In essence, his writings reflect his central concern with the process that humans use to construct their knowledge of the world (Driver, et. al., 1994). Piaget (1970) stated four factors which influence the process of intellectual development (Jacobs, 1984):

1. Maturation--adaptation to the physical and social world
2. Physical experience--acting on objects within a social context
3. Social transmission--experience with people and schemes invented by people within a cultural context
4. Equilibration--the intrinsic process which effects a balance or momentary equilibrium among the factors of maturation, physical experience, and social transmission; in reality, a balance between what is known and what the learner is trying to comprehend.

Equilibration is central to Piaget's theory of constructivism (Jacobs, 1984).

Piaget stated three components of intelligence: content, functions, or functional variants, and structures, or variants (Piaget, 1963; Wadsworth, 1971, p. 21). Content refers to observable behaviors, both sensori-motor and conceptual, which reflect intellectual activity. Because of the nature of content, intelligence varies considerably according to age and from child to child. Functions, also called functional invariants, are modes of action that do not change with maturation or experience. Functions (functional invariants) are invariant across both stages and content. Functions refer to the two characteristics of intelligent activity, organization and adaptation, which are stable and continual throughout the cognitive development process. Organization, according to Piaget, is “the accord of thought with itself” or the tendency toward integrating various parts of our experience into wholes and wholes into more comprehensive wholes. By adaptation, Piaget meant “the accord of thought with things, “ actually the tendency toward adjustment to our physical and intellectual world in increasingly flexible ways. Adaptation actually takes two forms: assimilation and accommodation. Assimilation is the tendency to change what we have encountered to fit our existing knowledge structures, to relate new knowledge to previously existing cognitive structures, and to act according to previous experience. Accommodation is the tendency to act, think, and feel as the situation demands, a change in structure, or to act in new ways depending on the immediate situation. Structures, or variants vary across both stages and contents and refer to organized aspects of intelligence, to the schemata or inferred organizational properties, which explain why specific behaviors occur. (Structures change with age or development, so a change in structures leads to development.) Individual structures are schemes or schemata. A scheme is whatever is generalizable or repeatable; schemes are instruments for assimilation. Reflexes are the earliest structures. Structures of knowledge are integrated into consistent patterns of thinking and acting, called stages.

Piaget (1963) broadly summarized four periods (usually conveniently referred to as stages) of cognitive development (Wadsworth, 1971):

1. Sensori-motor intelligence (0 - 2 years)
2. Preoperational thought (2 - 7 years)

3. Concrete operational (7 - 11 years)

4. Formal operational (11 - 15+ years)

Piaget’s equilibration represents the dynamics of knowledge growth (Rowell, 1989). Piaget (1970) wrote:

> The fundamental hypothesis of genetic epistemology is that there is a parallelism between the progress made in the logical and rational organization of knowledge and the corresponding formative psychological processes. (p. 13)

Piaget sought the unification of all knowledge growth at all levels-- individual, social, and historical (Rowell, 1989).

The viewpoint that knowledge is constructed is central to the learning theory of Jean Piaget, although he referred to himself as a constructivist only later in life (Piaget, 1970). Piaget's central emphasis involved the epistemology by which learners construct their knowledge of the world (Driver, et. al., 1994). Piaget thought students' capability to learn evolved with their developmental stage, whether sensori-motor, pre-operational, concrete operational, or formal operational. His conservation task serves to identify the formal learner. In classrooms in which Piagetian constructivism is followed, individuals become actively engaged through social interaction within groups to interpret and understand scientific phenomena (Driver, et. al., 1994).

If a theory exists by which students construct their own knowledge during formal learning by using previously acquired everyday concepts, then the same can be postulated about learning theorists in their effort to construct an acceptable theory of learning that can be viewed as the definitive theory of learning by the world of science education. After all, most constructivist theorists, including Vygotsky, have researched Piaget extensively and discarded some ideas which conflicted with their assumptions about knowledge, then interwove certain elements to construct their own learning theory through a process of interaction with scientific concepts held valid by the more credible world of sophisticated learning theory. With the difficulty science educators have of constructing the definitive construct theory, which ultimately explains how children construct their own knowledge, then reason exists for the challenge science educators face in understanding how children learn. A good theory of learning should accompany good instruction.

<u>Children's Ideas in Science</u>

Cognitive psychology has become an ever-expanding field of research into children's developmental conceptual understanding (Flavell, 1992). For much of the nineteen eighties, Piaget's conservation tasks represented the definitive example used to establish a child's level of understanding. According to Piaget, the child's developmental level determined the conceptual capability to conserve. In contrast, Vygotsky incorporated children's everyday and scientific concepts in analyzing conceptual understanding. Cognitive psychologists agree on at least two points:

1. Children undergo extensive and varied cognitive growth [during their development] between birth and adulthood.
2. Children are very active, constructive thinkers and learners (Flavel 1992, p. 998).

Such knowledge forms the basis for much of the research being conducted on learning theory. Learning theories reported in the research literature often focus on some method of knowledge construction to present children's ideas in science.

Children's ideas and the way those ideas are constructed have been the focus of a number of research studies (Leach, et.al., 1995, 1996a, 1996b; Osborne & Freyberg, 1985). Osborne and Freyberg (1985) conducted extensive interviews, not to evaluate whether children held acceptable scientific concepts, but to determine the focus of children's ideas or everyday concepts. In their interviews, the authors used a range of possible concepts that students might associate with a particular word (e. g., plant). Depending on their everyday and scientific knowledge, students have varying conceptual understanding of what constitutes a plant. To illustrate their procedure, the authors used cards of plants and plant parts similar to those used in a research study of 29 students by Bell (1981). Plant parts pictured included a carrot, grass, oak tree, and a seed. Bell found that some 10-, 13-, and 15-year-olds did not consider a tree a plant. More than half the students interviewed did not think of a seed as plant material. Other children considered a plant something that was cultivated; therefore, grass and dandelions were weeds, not plants. Furthermore, over half the students interviewed considered carrots and cabbage vegetables, and furthermore, did not extend the concept of vegetables to plants. Thus, at a given age the range of children's ideas in science can vary tremendously depending on their everyday and scientific concepts as indicated above.

A number of researchers have conducted studies on children's ideas in science. Children's ideas represent spontaneous understanding of everyday concepts learned from their experiences. Leach, et. al. (1995, 1996a, 1996b) and Osborne and Freyberg (1985) researched children's ideas in science. Osborne and Freyberg (1985) reported three general findings that form the theme of children's ideas in science:

1. From a young age, and prior to any teaching and learning of formal science, children develop meanings for many words used in science teaching and views of the world which relate to ideas taught in science.
2. Children's ideas are usually strongly held, even if not well known to teachers, and are often significantly different from the views of scientists.
3. These ideas are sensible and coherent views from the children's point of view, and they often remain uninfluenced or can be influenced in unanticipated ways by science teaching (Osborne and Freyberg, 1985, p. 12).

Osborne and Freyberg do not claim the general statements to be original, but indicate that the theme of children's ideas has been implied since the earliest writings of Piaget (1929). What Osborne and Freyberg do suggest is that the findings have been mostly ignored by teachers, curriculum developers, and in some cases, science education researchers.

Although Osborne and Freyberg consider some of Piaget's earlier studies, such as animism, egocentrism, and the relationship between language and thinking relevant to understanding children's ideas, Piagetian stage theory is problematic when trying to explain the broad questions of how children construct their ideas, and the difficulty involved in modifying their ideas. Vygotsky, another theorist who studied Piaget extensively, disagreed with the theory of egocentrism and based his views of children's understanding of concepts on the everyday concepts acquired from relationships with family, peers, and through experience, and scientific concepts resulting from formal schooling. According to Vygotsky, through language and everyday experiences children attempt to make sense of their world. The similarities and differences between children's everyday ideas or concepts and the concepts of scientists are of central concern to the teaching and learning of science.

Knowledge of how children acquire their ideas before formal schooling, and the difficulty in modifying their views needs to be understood by teachers and researchers (Osborne & Freyberg, 1985). Kelly (1969) suggested that from a young age, we are all scientists in some way. The child-as-scientist represents one view on how knowledge is constructed to explain the natural world and how it functions.

A child's everyday ideas or concepts, that is, what the child is already thinking, plays an important role as to how a child interacts with teaching, and subsequently, how the child responds to the learning process (Johnson & Gott, 1996). Interview interpretations of children's expressions have generated a range of widely accepted children's ideas, validly and reliably established (Driver, et. al., 1994). The rationale is that understanding the ideas or everyday concepts children bring to the classroom is a complex process, which may be limited by a constructivist position. Furthermore, children have different zones of proximal development, which impact their everyday and scientific concepts. In order to find out what a child thinks, the researcher must carefully interpret the child's response to specifically designed research questions. "Each person makes his or her own sense of the world, and can only use what he or she already knows (existing cognitive structure) to do this--we will call this a 'frame of reference.' It follows that each person's frame of reference differentiates his/her world to different extents and integral to this is language--the meaning of words. Given this, there is an inbuilt uncertainty in any communication between two individuals" (Johnson & Gott, 1996, p. 563).

Communication between two individuals always has what is called a "translation interface" (Johnson & Gott, 1996, p. 563). The translation interface may be traversed twice. First of all, the child could actually be answering a question other than the one asked, either as a result of misinterpreting the question or from the standpoint of the teacher not asking the intended question. Children have different everyday concepts from which to interpret questions. Second, the researcher could interpret the child's answer in a way that did not convey the same meaning as the child had intended.

Experiences in the lives of learners always involve and are strongly influenced by social interaction through the use of language and speech. One can know only what is constructed by oneself within a social context (Yager, 1995). The Russian epistemologist, Lev S. Vygotsky, who studied Piaget closely, is identified with social constructivism. Vygotsky viewed language and speech as psychological tools for mediating learning. To what Glynn and Duitt called mental models, Vygotsky referred to as everyday or spontaneous concepts. Instead of conceptual models, Vygotsky preferred scientific or non-spontaneous concepts (1962, 1978, 1987).

The learning theory of Vygotsky pertaining to everyday concepts and scientific concepts serves as the model for the theoretical framework of this research study. Vygotsky developed his views on the relationship between formal instruction and cognitive development, partly on the basis of his exploration of the work of other cognitive researchers, including Piaget, partly through application of his practical knowledge, and partly on the basis of results of empirical investigations by his collaborators and students (van der Veer & Valsiner, 1991). Studies by his students were mostly master's theses, which were never published. Vygotsky wrote extensively on the development of concepts. Before children actually develop true concepts, they think in complexes, forming pseudoconcepts then potential concepts (Vygotsky, 1994). According to Vygotsky, all higher psychological functions are mediated processes, mediated by signs or words to solve a specific problem.

The roots of concept formation go back to genetic development in early childhood, but thinking in concepts does not occur until the maturation process in adolescence. In his study of *Thought and Language*, Vygotsky (1986) concluded that a most important event occurs around age two when developments in thought and speech, separate until then, come into contact and engender newly available mental processes--verbal thought and intelligent speech (Kozulin, 1990).

For the purposes of this research study, Vygotsky's theory of social constructivism complements Piaget's theory of developmental constructivism. Among the most central of Vygotsky's views is the belief that human development varies fundamentally from the development of animals because humans can use tools and symbols to create cultures (Lefrancois, 1995). Cultures grow and change to determine how learning and thinking take place. Three basic themes permeate Vygotsky's sociocultural approach to the mind (Wertsch, 1991, p. 19):

1. A genetic, or developmental reliance to analysis of mental functioning, thought and speech.
2. Higher mental functioning of the mind results from the social life of the individual.
3. Human action, both socially and individually, is mediated by tools and symbols.

According to Vygotsky, concept development in children is best approached by a method that combines both the word, or verbal symbol, and the object, or perceptual material, what has come to be known as double stimulation. This method focuses on functional conditions of concept formation rather than on traditional methods, which separate the two parts (Vygotsky, 1962, p. 53). Furthermore, this method asserts that a concept is an active and changing part of the intellectual process, not an isolated, ossified formation. In the process of combined conceptual development, a child is constantly engaged in communication, understanding, and problem-solving. Memorizing words, then connecting them to objects does not result in concept formation. Concept formation occurs when a problem can be solved only through the formation of new concepts. Long before age twelve children understand the experimental task, but they cannot form new concepts until then. Essentially, children communicate with words long before they reach the level of thought connected with complete conceptual development (Vygotsky, 1962, p. 55).

Everyday and Scientific Concepts

Research by Shif, a student and collaborator of Vygotsky (Daniels, 1996, p. 11; Kozulin, 1990, p. 167), focused on seven and ten-year-old children's understanding of relationships between causal (*because*) and adversative (*but, although*) concepts. The children were asked to complete sentences pertaining to content of everyday situations, such as "the child fell off a bicycle because . . .,"or to formal school concepts. In addition, she conducted Piagetian-like interviews to evaluate the child's comprehension of the concepts. This study was theoretically based on the distinction between "everyday" concepts and "scientific" concepts. The results led to the convincing qualitative conclusion that scientific concepts developed more rapidly and seemed to precede the development of everyday concepts. The purpose of education, or schooling, then, is to develop scientific concepts ahead of the development of everyday concepts. Vygotsky argued that both everyday and scientific concepts were important in the development of mature concepts. His fundamental conclusion was that if scientific concepts are acquired through education, and everyday concepts represent development, then education precedes and supports development. The two concepts are defined as follows:

1. <u>Everyday concepts</u>
    a. Formed as a result of a child's independent thinking and experience (Vygotsky, 1962, p. 84)
    b. Acquired socially without formal instruction
    c. Spontaneous
    d. The child's own spontaneous reflections on immediate, everyday experiences (Kozulin, 1990)
2. <u>Scientific concepts</u>
    a. Formed on the basis of organized, systematic, hierarchical, thinking, and acquired through formal instruction
    b. Logical, hierarchical organizations that originate during classroom instruction (Kozulin, 1990)
    c. Nonspontaneous
    d. Changeable, dynamic structures

Essentially, Vygotsky was concerned about the interrelationship between a child's everyday concepts and scientific concepts (Howe, 1996. p. 38; Kozulin, 1990). Kozulin (1990) discussed scientific and everyday concepts as follows:

> Scientific concepts themselves do not necessarily relate to scientific issues--they may represent historical, linguistic, or practical knowledge--but their organization is "scientific" in the sense of formal, logical, and decontextualized structures.

> Everyday concepts, on the other hand, emerge spontaneously from the child's own reflections on immediate, everyday experiences; they are experientially rich, but unsystematic and highly contextual. In this sense, they are not concepts, but "complexes." (p. 168)

Through formal instruction, scientific concepts relate to and actually become the child's everyday concepts (Hedegaard, 1996, p. 172). Instruction in scientific concepts deemed essential by teachers and curriculum planners, guides the direction of development of the child. The difference between the level of accomplishment with adult guidance and the level of achievement independently is the zone of proximal development (Hedegaard, 1996, p. 172).

Vygotsky wrote that the central fact of his theory is mediation between the child and adult, especially on the nature of social interactions. The strength of scientific concepts lies in the child's capacity to use the concepts voluntarily (Moll, 1990, p. 9; Vygotsky, 1987). In contrast, the weakness of everyday concepts is their lack of systematic organization and the child's inability to manipulate them voluntarily. Vygotsky focused on the manipulation of language in the development of scientific concepts and as an important characteristic of formal schooling.

Inagaki (1990) concluded that students normally use their knowledge flexibly and maximally in the process of everyday scientific reasoning. However, the extent of correctness differs among the sciences, with biology appearing to have the edge. First, children are more likely to use their knowledge to reason scientifically in biology because of their previously acquired knowledge and everyday experience with the environment.

Second, reasoning in biology involves realistic situations. Third, students are motivated to find plausible explanations for answers to questions pertaining to their environment.

The leading idea of Vygotsky's research in the development of thought and language in childhood was that concepts evolve. The main qualitative result from the study of concept formation in children was that the level of true conceptual problem solving is achieved during adolescence. Instead of true concepts, younger children utilize functional equivalents of concepts, which differ from real concepts in the type of generalization and in how the words are used to designate the generalization (Kozulin, 1990). According to Vygotsky, "the central moment in concept formation, and its generative course, is a special use of words as functional tools" (Vygotsky, 1986, p. 107).

Vygotsky identified his idea of a concept (thinking in " heaps") by experimentally having children group blocks of different attributes, including color, size, shape, and height. Vygotsky explained three major types of preconceptual representations: syncretic grouping, thinking in complexes, and potential concepts (Vygotsky, 1962, 1986). Kozulin (1990) stated that the types of preconceptual representations should not be mistakenly identified as natural stages in a child's cognitive development, but rather as methodological devices to distinguish what appears to be the most pronounced form of concept formation at a given age. Furthermore, researchers should note that older children and adults often revert to the more primitive preconceptual types of representation depending on their interpretation of a given task and the strategy chosen for solution.

The first type of preconceptual representation, uniting items in groups, what Vygotsky called syncretic problem solving, involves the building of syncretic images from an unorganized stockpile of perceptions. In syncretism, objects are grouped subjectively through:

1. Trial-and-error, which is pure syncretism.
2. Egoistic selection, which is based on the child's field of vision.
3. Combinations, which are collections or groupings previously arranged by trial-and-error or ego-centrically.

The second major type of representation involves thinking in complexes, which implies making concrete and factual objective connections or associations into groups, such as in members of a family. Thus, thinking in complexes links subjective groupings to facts. Thinking in complexes, for example, grouping items according to attributes, is the basis of language development, having to do with the way we find word meanings in different contexts. Through thinking in complexes, concrete elements are grouped subjectively and by facts in one of five types of complexes:

1. The associative complex, as with members in a family; all individuals related to a given person have the same family name.
2. The collection complex, in which collections, or sets, are grouped according to different attributes.
3. The chain complex, in which an object is connected to another by a common attribute, to the next object by a different attribute, and to still another object by yet a different attribute.
4. The diffuse complex, is a stable form of thinking, yet an undefined and vague unifying of attributes in which features glide past one another with

no firm boundaries because the thinking demanded is outside the child's practical knowledge.

5. The pseudoconcept, representing a bridge to the formation of concepts, corresponds to a true concept phenotypically because of strong similarities to a scientific concept, yet genotypically is only an associative complex of concrete similarity.

Vygotsky elaborated:

> The pseudoconcept is the most common form of complex in the preschooler's real life thinking. It is a form of complexive thinking that prevails over all others. It is sometimes the exclusive form of complexive thinking. Its wide distribution has a profound functional basis and significance. This form of complexive thinking gains its prevalence and dominance from the fact that the child's complexes (which correspond to word meanings) do not develop freely or spontaneously along lines demarcated by the child himself. Rather, they develop along lines that are preordained by the word meanings that have been established in adult speech. (1987, p. 142)

A child at the complexive thinking level thinks of the same objects or same concept based on the accepted word meaning as an adult, but in a different way. Thinking in complexes serves to establish relationships between word meanings and objects for future generalizations in concept development.

The third major type of representation, potential concept, includes the elementary function of abstraction in which children can distinguish between essential and nonessential attributes. Conceptual development ultimately occurs then in two representations consisting of the formation of:

1. A potential concept, developed in the domain of concrete thinking, in which a child isolates a group of objects unified according to a single common feature.
2. A concept, (genuine concept or concept-proper), involves the mastery of abstract thinking combined with advanced complex thinking, a re-synthesis of abstracted traits into the predominant instrument of thought.

Vygotsky discussed potential concepts in the form of pseudoconcepts. Although it retains its "thinking in complexes" substructure, a pseudoconcept functions very similarly to a concept, and serves to pinpoint the borderline between prelogical and logical thought. The main distinguishing feature of the pseudoconcept is that it is so often indistinguishable from the concept, phenotypically, that adults do not notice the difference. For example, if given a red triangle as a model from a group of shapes, the child will select all the other triangles from the experimental group, based not on abstract thinking but on concrete similarities. Finally, the formation of progressively more advanced concepts is based on the adolescent's capability to become conscious of processes that are mastered unconsciously.

In experimental studies of adolescent intellectual processes, Vygotsky (1962) observed that all representations of concept development co-exist during the process of development, predominating at different times and in different contexts, yet at the same time, each building on previous progress. Thus, as the more primitive syncretic and complex forms of thinking gradually diminish, potential concepts are used less often, and true concepts begin to be used with increasing frequency. Even after the adolescent develops the use of true concepts, the more elementary forms of thinking still predominate adolescent thinking. The adolescent as well as the adult will apply a concept correctly in a concrete situation, but will have difficulty expressing the concept in words. The adolescent has further difficulty when a task requires applying a concept he has learned in a particular context to a novel situation. Still even more difficult than transferring the meaning of a concept is defining the concept on a purely abstract plane without reference to a concrete situation. The greatest difficulty is the application of abstract concepts to new concrete situations. Thus the transition from the abstract to the concrete proves as difficult as progressing from the concrete to the abstract. Vygotsky (1962) stated:

> When the process of concept formation is seen in all its complexity, it appears as a 'movement' of thought within the pyramid of concepts, constantly alternating between two directions, from the particular to the general, and from the general to the particular. (p. 80)

In summary, with word meaning as the guiding function, concept formation, according to Vygotsky, progresses from thinking in complexes to the formation of potential concepts and finally to genuine concepts. Indeed, word meaning is the basic unit of verbal thought (Vygotsky, 1962).

The final step in Vygotsky's study of concepts was to investigate the distinction between spontaneous or "everyday" concepts and "scientific" concepts. Students use both types of concepts according to context (Kozulin 1990, p. 168). Everyday concepts (complexes) arise spontaneously from a child's experiences, are very contextual, and lack coherence. On the other hand, scientific concepts originate during formal instruction, are logical and coherent, and are decontextualized. Once concept development is complete, the adolescent possesses an "unprecedented *modus operandi"* (Vygotsky, 1994, p. 259) for intellectual problem solving.

Vygotsky (1986) concluded that younger children are preconceptual. Children move through a sequence of preconceptual representations of heaps, chain-concepts, collections and pseudoconcepts. True logical concepts develop during adolescence with the construction of taxonomic hierarchies. To Vygotsky, the problem of conceptual change in childhood was viewed in terms of the difference between everyday and scientific concepts (Nelson, 1996). Vygotsky viewed the development of everyday and scientific concepts as related and constantly influencing each other. In fact, the two form a single, unifying process of concept formation, which is affected by varying internal and external conditions. To Vygotsky, the use of language was essential for the transition from everyday to scientific concepts. He viewed the most important characteristics of mature thought as (1) generality and (2) systematicity, which are not a part of the concepts of preschool children; scientific concepts are acquired through formal instruction (Nelson, 1996).

The foundation of a concept is formed from several concrete ideas. For example, consider the concept of a tree (Vygotsky, 1994). Trees have different attributes in the form of size, shape, height, color, leaves, trunks, roots, and whether gymnosperms (conifers) or angiosperms (flowering). Assimilation of the similar parts of trees leads to the true concept of a tree. Likewise, consider the concept of a flower. A child learns the collective term *flower*, then associates types of flowers, such as roses, orchids, or gardenias as belonging to the collective word, *flower*. Both trees and flowers belong to the broader category of plants. Thus, the fact that a child may not consider a tree or a flower a plant unless the full concept of a plant has been developed during everyday and scientific concept formation is understandable.

Vygotsky's research on everyday and scientific concepts has important implications for both education and cognitive psychology. A central theme in Vygotsky 's over-all theory was the investigation of how formal schooling develops higher thinking capabilities by providing students with cultural experiences that form logical memory. He viewed instruction as basically different from the spontaneous learning occurring in everyday contexts. On the other hand, he theorized that everyday experiences had a "transforming impact on the school child's mental development" (Panofsky, et. al., 1990, p. 251). The type of out-of-school, 'street-wise,' experiences children have determine their levels of creative problem-solving (Wassermann, 1982). For example, children who live in rural areas or have observed animals in a zoo or natural setting would be more likely to know how to weigh a horse, for example, than those who live in rural or urban settings without such experiences.

Central to Vygotsky's research is the distinction between spontaneous or everyday concepts and non-spontaneous or scientific concepts (Panofsky, et. al., 1990). Everyday concepts are defined in terms of the perception, function, or context of their development as a result of everyday, concrete experiences, in much the same way a child's oral language develops. In contrast, scientific or non-spontaneous concepts are learned as a result of analytic or formal procedures, in relation to a system of concepts, much like learning a second language. Learning scientific concepts or a second language depends and builds on the child's everyday experiences (Vygotsky, 1987). Thus, everyday knowledge mediates the learning of scientific knowledge; that is, the formation of scientific concepts is dependent upon and builds upon a pre-existing complex of everyday concepts. For example, a child's everyday observations of pollinators around flowers mediate an understanding of scientific concepts pertaining to pollination explored in the classroom.

The development of scientific concepts during formal instruction requires consciousness and volition on the part of the child (Panofsky, et. al., 1990). In contrast, everyday concepts are acquired spontaneously. During instruction the child must consciously manipulate and analyze the object of instruction. For example, a child learns to define terms, to understand concepts in collaboration with an adult. Scientific concepts eventually acquire concrete meanings, and everyday concepts eventually become rational and accessible to conscious will. The contrast between everyday and scientific concepts can be understood in relation to research on the acquisition of script-like knowledge that develops spontaneously from everyday experiences (Nelson, 1983). Nelson defined scripts as "generalized event representations of the child's earliest recurring experiences; they are contextualized wholes such as the 'restaurant script' or the 'preschool script' that consist of a sequence of events that join to form a meaningful idea. Over time, concepts are derived from scripts by a process of analysis or partitioning" (Panofsky, et. al., 1990, pp. 253-254).

Panofsky et. al. (1990) viewed Vygotsky's everyday concepts as those derived from scripts, as in Nelson's scheme. Such concepts derive their meaning from perceptual, functional, and contextual qualities of their referents. Nelson's work supplements Vygotsky's earlier work in that observation of everyday cognition is emphasized. For example, in focusing on a biological referent, concepts can be classified in either script-based or scientific taxonomic ways. Using a script organization, a child may group *robin* and *butterfly* together because 'both fly in the air.' Alternatively, the child may group robin and ostrich taxonomically, for example, because they are birds within 'a system of relationships of generality' (Vygotsky, 1962, p. 92). As a child moves from script to taxonomic classification, "the emphasis has shifted away from those aspects of linguistic signs to enter into decontextualized relationships, that is, relationships which are constant across contexts of use"(Wertsch, 1985, p. 103). Script-based concepts are significant as revealed by their commonality, connections, and systematicity children construct during their daily activities, although their constructions are not as sophisticated as the mastery of scientific concepts learned later in development. Vygotsky stressed the interweaving of everyday and scientific conceptualization, and referred to the role of transitional and intermediate concepts. Panofsky, et. al. (1990) conclude that cultural and family experiences contribute to the way spontaneous and systematic concepts become woven together during different developmental phases.

West and Pines (1985) viewed the patterns that emerge from the mosaic of ideas on learning as conceptual understanding. Conceptual understanding implies making one's own sense of the world by constructing one's own knowledge. West and Pines (1985) and Pines and West (1986) distinguished the same two sources of knowledge proposed by Vygotsky (1962):

1. The knowledge that children spontaneously acquire from their interactions with the environment.
2. The knowledge children acquire in a formal fashion through the intervention of the school (Pines & West, 1986, p. 585).

Vygotsky referred to spontaneous knowledge as everyday concepts and to formal knowledge as scientific concepts. Everyday or informal knowledge has numerous synonyms: 'spontaneous knowledge,' 'naive knowledge,' and 'gut knowledge' (Pines & West, 1985).

Although such terms may tend to downgrade the active sense-making constructing process, the importance of the conceptual understanding of everyday concepts that children have constructed about the world around them is not to be overlooked.

The spontaneous knowledge developed before formal schooling has a tremendous impact on children's capabilities and what will be learned during instruction. Children are born with a natural curiosity to learn about the world around them. From birth, they take in the world through their senses, spontaneously constructing a world viewpoint. Pines and West (1985) elaborated on spontaneous knowledge:

> This informal knowledge constitutes the child's total belief system about the world and how it works. Such knowledge is a product of efforts to make sense of the environment, tempered and manipulated through interactions with parents, peers, television, and other influences; it is influenced by language, by culture, and by other individuals. The primary characteristic of this knowledge is that it constitutes children's reality, something they believe! A secondary characteristic is that this knowledge is acquired in a rather haphazard fashion, over considerable time, and without any particular predetermined direction. The child does not, for instance, set out to learn the nature of the earth as a cosmic body. The children's senses reveal a flat earth, but they also see in photographs from space that it is round. At any particular time in children's lives they have a particular conception of the world which they believe, think of as reality, and assume is shared by others. (p. 586)

Children's use of spontaneous knowledge has tremendous impact on influencing their formal learning and even their willingness to learn. The teacher is all too aware of innocent young children's eagerness to explain previous knowledge in a formal classroom. As children mature, however, the willingness of some to participate is often inhibited by fear of embarrassment or negative remarks from their peers.

In contrast to spontaneous knowledge, formal knowledge represents a product of planned instruction, and usually occurs in a school setting. Some synonyms for formal knowledge include 'curricula knowledge,' 'school science,' and Vygotsky's scientific concepts or scientific knowledge. Formal knowledge has two characteristics (Pines & West, 1985):

> The primary source and characteristic of this knowledge is authority: It is "correct;" it is what the book says, what the teacher preaches from the pulpit. Formal knowledge is approved by the consensus of respected adults who are usually older and more highly regarded than the student. The second characteristic of formal knowledge is that it is acquired via a goal-directed process. Typically, students set out to learn a particular body of knowledge are expected to master it in a certain time period. Students are usually then expected to demonstrate, by and large through tests, what they have learned. (p. 586)

Spontaneous knowledge profoundly influences formal knowledge. In fact, learning is always a result of interaction between spontaneous and scientific concepts (Pines & West, 1985). A child's mind is not a vessel to be filled or a tabula rasa on which knowledge can be inscribed during formal instruction. Instead, a child's mind functions to be challenged to construct knowledge using spontaneous concepts.

In his writing, Vygotsky (1962) used the vine analogy in reference to the relationship between thought and language. Vygotsky referred to both thought and language as vines, each having a separate source of origin but becoming so intertwined by adulthood that they were inseparable. Pines and West (1986) and West and Pines (1985) have adopted the vine metaphor as a useful framework to describe the interaction between informal and formal learning as well. Emphasis is placed on the vine metaphor as a heuristic tool, not to be taken literally, but to serve a useful purpose. In using the vine analogy, spontaneous and scientific knowledge may be thought of as separate vines having different sources of origin:

> The spontaneous knowledge is a product of a relatively long ontogenetic development within a culture, itself within a physical environment of experiences; the formal knowledge is a planned intervention imposed by the school. There is no clear-cut demarcation--both are experiences--yet the spontaneous knowledge is, so to speak, a more internally experientially (phenomenological) based belief system than the formal knowledge imposed by the authority of science and under the auspices of the educational system. (p. 587)

In the vine metaphor, spontaneous knowledge is represented by an upward growing vine (to emphasize it as being a part of the organic growth of the learner). On the other hand, formal, or scientific knowledge is represented by a downward growing vine (in reference to its being imposed by the authorities or powers that be). To the constructivist, meaningful learning of scientific concepts involves varying degrees of integration or intertwining of the two vines.

Several possible relationships emerge whenever the two vines, spontaneous and scientific knowledge, make contact. The relationships range from immediate affinity, toward intertwining partially or completely, to total rejection. To use other metaphors, the concepts can either mix completely as two fluids, such as alcohol and water mix, or have no mixing as with oil and water. An additional metaphor is likened to the human immune system, which either accepts or rejects an externally induced agent (Pines &West, 1986).

Pines and West (1986) described four over-lapping prototypes that can be used to describe learning situations in varying degrees of intertwining of the vines:

1. The conflict or incongruous situation,
2. The congruent situation,
3. Formal symbolic/zero-spontaneous situation, and,
4. Spontaneous, or uninstructed situation.

The example used to represent a conflict or incongruous situation is that one of Newton's laws states that a body will continue in constant motion unless acted upon by some external force. Students are surprised to see that a puck on an ice table will continue in motion uninterrupted with just a single blast of air, in conflict with their prediction that a constant blast of air would be needed. The two vines clash, thus causing conflict between spontaneous and scientific concepts that must be resolved. The congruent example cited is Ausubel's description of the human body as a sack filled with blood. Indeed the students found that no matter where the body was pricked, bleeding would occur. As such, the child's existing concepts are simply reinforced. In prototype three with zero-spontaneous knowledge as in learning organic chemistry, there is no intertwining, so learning may become complex and problematic. Finally, in prototype four, there is no formal knowledge to intertwine with extensive spontaneous knowledge as in mythology. Children have vivid imaginations on mythology, so learning is immediate. Conceptual development is described as involving much branching and merging of the vines (Pines & West, 1986).

Piaget and Vygotsky

The theories of both Piaget and Vygotsky are known for their knowledge of students' construction of thinking (Bodrova & Leong, 1996). Piaget and Vygotsky were contemporaries. Vygotsky was acquainted with Piaget's early works, and Piagetian ideas permeate his writing. Both Piaget and Vygotsky agree that a child's development involves a series of qualitative changes (Bodrova & Leong, 1996). Piaget believed that developmental changes occur in stages and cannot be changed by the learning. Vygotsky differed with Piaget on development. According to Vygotsky, everyday concepts should serve as a gauge of a child's cognitive developmental progress. Vygotsky believed that children develop in a social context through their zone of proximal development, a continuum of emerging learning, and that mental tools assist learning. Both Vygotsky and Piaget believed that children construct their own conceptual understanding, and that the understanding can be restructured with development and experience (Bodrova & Leong, 1996)

Mapping progression in children's thinking about the nature of particular ideas and concepts in science reveals influence by both social factors (mainly through language) and through experience with phenomena (Leach, et. al., 1995). Social influences refer to the everyday ways of knowing and discussing scientific phenomena under consideration. Solomon (1987) referred to the everyday ways of knowing, which are often taken for granted by children as well as adults, as 'life world knowledge.' Because real life worldviews are part of a common culture, such views may or may not be in accord with the scientific viewpoint. Leach, et. al. (1995) cited an example of children's conceptions of the everyday way of knowing that 'plants feed from the soil' as an example of a firmly established everyday concept. The everyday concept is counter to the scientific point of view, and is unsupported by any direct evidence unless through circumstantial evidence, such as adding 'plant foods' or fertilizers to the soil.

Children's basic assumptions on the nature of scientific phenomena, that is, their ontologies, change with experience in the natural world, especially in regard to ecological phenomena (Leach et. al., 1995). Children observe pollinators on flowers, cockleburs on their clothing or winged maple samaras floating in the air, and cattle grazing on the grassy hillside, experiences which are mediated by social influences. Regardless, as children are introduced to scientific concepts of interest in their schooling, their extensive personal history established through observing, listening, talking, experiencing, and thinking during the formation of everyday concepts impacts their learning and understanding of long established scientific concepts. As such, progression in learning may occur as a result of formal schooling or during informal learning situations and conceptualized as a dynamic and ongoing process, which includes additions, deletions, enhancement, and changes in their existing ways of thinking depending on the context in demand (Leach, et. al., 1995). Osborne and Wittrock (1983) and Wittrock (1985) proposed a model of science learning which promotes an interaction between the students' existing knowledge and thinking and the scientists' models of physical and biological phenomena. To promote science learning, teachers should understand how students use previously learned, informally acquired concepts and ways of thinking to generate meaning from ideas or events explained in more sophisticated fashion by scientists. Wittrock (1985) preferred *generating* to constructing in his generative learning model. He described the over-all concept of science learning and teaching as a means to stimulate learners to generate (construct) new and improved understandings of scientific phenomena through the assimilation of new concepts to old frameworks, or by the accommodation of new frameworks from old frameworks. Strike and Posner (1985) indicated that science learning often requires learning a conceptual framework that differs from the one the student has previously learned. Learning is a process of inquiry involving rationality, which means relating one's previous learning to one's current ideas.

Young people's everyday knowledge has some obvious characteristics (Claxton, 1993). First, their theories are piecemeal, or fragmented, and local. Second, for the most part their "minitheories are developed in response to particular experiences, predicaments or needs, that work well enough on their homeground but whose limits of applicability--what Kelly (1955) called a theory's 'range of convenience'--may be rather circumscribed" (Claxton, 1993, p. 46-47).

Sprod (1997) concluded that implications from his study of social constructivist discussions in classrooms provide a tool for research in how children learn. His research was based on a classroom study using Perkins' conception building model (1994), consisting of patterns of thinking called epistemic games or epistemic episodes, which stimulate thinking through goal-directed conversations. Perkins claims that the goal of the conversations is to 'construct models or sets of interrelated models about a topic' (Sprod, 1997, p. 913). Perkins (1994, p. 94) included five earmarks of conception building through conversation:

1. Broad guiding principles help make sense of a topic.
2. Questions involving evidence mixed with critique of the concept.
3. Interlacing the concept with multiple frames of reference.
4. The purpose of the inquiry evolves as part of the inquiry.

5. A conceptual landscape emerges with many aspects, not all of which may be included in the discussion.

Each contribution in the conversation is written and placed in a *structured heap* on the table. Perkins (1994) summarized:

> The epistemic games must all be seen as social constructions, evolved through historical processes, acquired by today's thinkers, and deployed as shared symbolic vehicles that aid in the organization and communication of thought . . . they provide a 'syntax' for open-ended inquiry. (p. 94)

Sprod (1995) explained that the process of acquiring a syntax for open-ended inquiry begins in early childhood. Syntax implies a systematic way of developing learning.

Classroom discussions involving constructivist learning theory not only allow students to construct scientific content to add to the conceptual landscape, but also represent a powerful method to continue socially constructing the tools of thought. The constructivist landscape presented indicates that teachers must avoid thinking that a concept can be covered in a single lesson. Sprod (1997) stated:

> Complex conceptions are built through repeated social revisiting; we need to re-walk the landscape many times, using many paths, with many companions before we can claim to know it. This is the true idea behind Bruner's spiral curriculum: not that facts must be imbibed again at intervals, but that ideas need to be re-explored to build their complexity . . .There are implications here for curriculum planners, who like to take content areas of

> subject domains and split them up into units to be covered, often at breakneck speed. No one discovers a landscape by driving rapidly along the highway across it, even if they do it everyday. (p. 920)

Children are not necessarily expected to clearly understand what knowing a concept scientifically means after every lesson, but viable progress is made through an awareness of inductive reasoning (Sprod, 1997). Conveying the nature of scientific knowledge as a means for the learner to re-describe the world by constructing models in the imagination was evident in the case of a child who requested to view the sun, not as rising in the morning and setting in the evening, but as spinning in space (Hesse, 1963). Thus, each child possesses an everyday conceptual understanding stated according to context. The everyday concepts will eventually mesh with scientific concepts through formal schooling.

Through his own research and that of his students and colleagues, Vygotsky discovered that children's capability to learn differed according to age and mental development. He called the difference in learning between the ages of eight and nine or eight and twelve, for example, the zone of proximal development (ZPD). He defined the zone of proximal development as

> the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers. (Vygotsky, 1978, p. 86)

Valsiner elaborated

> The ZPD is a term that helps us to capture those aspects of child development that have not yet moved from the sphere of the possible into that of the actual, but are

> currently in the process of becoming actualized, interdependently with the activities of the “social others” (Valsiner, 1987, p.107). According to Vygotsky, a child's actual developmental level pertains to functions that have already developed or matured. On the other hand, the zone of proximal development (ZPD) defines those functions that have not yet matured, but are in the process of maturation, functions that will mature tomorrow but are currently in an embryonic state (Vygotsky, 1978, page 86).

Vygotsky stated that the ZPD was analogous to the development of "buds" or "flowers, " whereas actual development was analogous to "fruits," the end product of development, or what has been mastered. To extend the concept further, as students continue to mature and master higher order problem solving, then "buds" or "flowers" should perennially mature into "fruits, thus establishing the desired level of conceptual understanding. In analogy, everyday concepts represent students’ beginning level of understanding, and scientific concepts indicate mastery.

Vygotsky’s general views on the development of higher mental functions postulated that mental functioning occurs first between people in social interaction and then within the child on the psychological plane. This implies that mental functions, such as thinking, reasoning, problem solving, or logical memory, can be carried out in collaboration by several people (on the interpsychological plane) as well as by an individual (on the intrapsychological plane). That is, dyads or groups as well as individuals can be agents that think and remember. Vygotsky’s approach suggests that to understand individual cognitive growth it will be fruitful to examine specific patterns of social interaction in which children participate (Rogoff & Wertsch, 1984, p. 1-2). Vygotsky was more concerned about a child’s potential than the actual level of development. He further argued that instruction must exceed the level of a child’s development. The ZPD then serves as a tool to advance the intellectual development of the child, to progress from everyday to scientific conceptualizing.

Vygotsky's theory of genetic development emphasizes the intrinsic social nature characteristic of all human activity. Children acquire their everyday concepts through their social relationships and activities. As their everyday concepts are refined by formal instruction within their ZPD, scientific concepts then receive focus and social reorientation. Vygotsky's zone of proximal development:

> is typically thought of as each person's range of potential for learning, where that learning is culturally shaped by the social environment in which it takes place. The ZPD brings into play the three themes that Wertsch (1985) finds central in Vygotsky's theoretical framework: a reliance on a genetic (developmental) method, an assumption of the social origins of consciousness, and a claim that mental processes are mediated by tools and signs. (Smagorinsky, 1995 p. 193)

Mediation is central to the use of tools. Vygotsky viewed self-regulation through the use of signs in communication as characterizing psychological growth. As a tool, speech creates signs in the form of words that serve to structure individual development, with signs serving as tools for both regulation and mediation (Smagorinsky, 1995). Through observations of his own environment, Vygotsky recognized that speech-generated signs represented the primary means of mediating culture within everyday contexts, and that scientific or decontextualized thinking was the highest level of conceptual development using the sign system

Research studies probe students' developing and multiple ways of knowing in order to establish how children utilize the ZFM/ZPA complex in trying to make sense of the world around them through assistance by adults in reaching their ZPD. Everyday concepts and the ZFM/ZPA complex impact the learning of scientific concepts. The environment of the developing child is surrounded by sets of boundaries, structured in a way that defines different zones. Consequently, the developing child is contextually involved in relationship to the culturally and physically structured environment. Assistance from parents, siblings, peers, teachers, and others who play varying roles in the changing environment of the child guide the child's actions in the structured environment (Valsiner, 1987).

The zone concept has as its origin the field theory research of German-American psychologist Kurt Lewin in the 1930s. Lewin's actual use of the zone concept pertained to the question of boundaries in life space that occupy an area of differing width (Valsiner, 1987). His concept of boundary was defined in connection with force field theory. According to Lewin's force field theory, individuals are interdependently linked to their environment. The structure of the person-environment field (P-E) is characterized by a constraint, boundary, or zone consisting of different forces that guide the person's development over time through changes in the field structure. For example, developing children would view a frozen pond differently depending on their developmental level and concept of a pond. Valsiner (1987) discussed three zone concepts pertaining to the socially structuring activity of the developing child: Zone of Free Movement or Zone of Freedom of Movement (ZFM); Zone of Promoted Action (ZPA); and Zone of Proximal (Possible) Development (ZPD).

Within the context of relationships in a child's environment, the child's freedom of action and thinking is limited by constraints that define the Zone of Free Movement or Zone of Freedom of Movement (ZFM) (Valsiner, 1987). The ZFM provides structure for the child's (a) accessibility to varying areas in the environment, (b) access to different objects available in an area, and (c) ways of acting with objects available in the accessible area. During development the child sets up and internalizes ZFMs in thought and feeling, which provide a structural framework for the child's cognitive activity and emotions. The ZFM is a social structure because it is based on adult cultural interaction, and it is a cognitive structure because it organizes child-environment relationships. A number of properties characterize the ZPM:

1. It is always based on the child's relationships with the structure of the environmental setting at a given time.
2. It is based according to the meaning of different aspects of the environment depending on the leading other person in the social setting.
3. The ZFM is constructed on the basis of the parent's understanding of what the child can do in the environment.
4. The ZFM is reconstructed as the child and adult enter a novel environment (p. 98).

Thus the ZFM becomes a cognitive control mechanism to keep the child within a culturally acceptable area of thought and action. "The ZFM is simultaneously a structure of the child's actions within the environment at the given time, and the future structure of the thinking of the child” (Valsiner, 1987, p. 98).

If the ZFM is conceptualized as an inhibitory boundary, then its counterpart, the Zone of Promoted Action (ZPA) is viewed as a mechanism to advance new skills. The ZPA represents a set of activities, objects, or areas within the child's physical environment that stimulates intellectual development. For example, the teacher may set up a science activity to encourage students to learn about the interdependency of plants and animals. The ZFM and the ZPA then serve as mechanisms functioning jointly to organize canalization of children's development (Valsiner, 1987). Canalization pertains to the pathway of gradual guidance and direction mediated by adults in the child's development. According to Waddington (1970), the construction of developmental pathways has accompanying self-stabilizing characteristics that serve to restrain variation of the organism-environment system as it changes over time. Development is canalized in a direction that is indeterminate but adaptable to unexpected environmental changes, yet with exact prediction of the future depending on constraints of the canalizing system. Valsiner (1987) invoked two modifications in Waddington's canalization concept as used in the current context. First, childhood constraints vary over time depending on the care of adults within the system; second, the child can alter developmental constraints. Canalization then becomes a gradual process of building further progress as the child develops in the direction of new structures, forming beliefs, logical reasoning, and social adaptation. ZFM and ZPA work jointly as mechanisms of canalization of children's development. Valsiner (1987) summarized as follows:

> The ZFM and ZPA are psychological means through which the child's development is gradually socially canalized by shaping his relationships with the environment. The ZFM reflects the current structure of child-environment relationships, and the ZPA

> reflects the desired direction of the child's further development. Whether or not the expected direction is indeed going to become actualized in future development depends upon how the particular aspect of child-environment relationships that is actively promoted by the adults (i.e. lies within ZPA) relates to the child's current motor and cognitive capabilities. The latter can be conceptualized through the use of the concept of the 'Zone of Proximal Development.' (p. 106-107)

Valsiner (1987) stated that the ZPD plays a decisive role in the child's intellectual development since it provides the link between the ZFM and ZPA. Dependent upon what is important to a child at a given time, the ZFM/ZPA system relates to new content that is promoted by the ZPD. The concept of the ZPD then relates to the types of developmental advancements possible for a particular child at a given time in ontogeny. Once a child has learned a skill or concept through the help of one adult within the boundaries of the ZPD, another adult cannot repeat the process, thereby indicating the empirical unverifiability of the full range of the ZPD. Only the actualized part of the range of possibilities of the ZPD may be available for empirical study, whereas all aspects of the ZFM and ZPA can be empirically verified (Valsiner, 1987).

Valsiner (1987) discussed some alternative conceptualizations to the ZFM/ZPA/ZPD concept, such as scaffolding, and scripts (discussed earlier), which enhance understanding of the zone concept. Scripts are conceptual representations of sequenced events, which can become activated when needed. Bruner (1984) used the metaphor of scaffolding to explain how adults assist with child development during tutoring to help the child accomplish a specific task. Child development during tutoring was ultimately linked with Vygotsky's ZPD concept. Scaffolding relates to how an adult builds a supporting structure around a student, especially during tutoring. The supporting framework then assists the child in learning a task more generally and in a wider context than if learning unassisted (Wood, 1980). As in an apprenticeship, then, the adult assisted the child in mastering a concept that might otherwise go unmastered.

Thus scaffolding, as presented, relates to the ZFM and ZPA concept (Valsiner, 1987). Once the child is involved in a certain task, the adult offers encouragement be setting up constraints to help the child (ZFM), then suggests a set of actions (ZPA) which contribute to the solution of the identified problem. Once one problem is solved, 'de-scaffolding,' serves to rearrange the constraints in preparation of solving another problem. Depending on how the adult constrains and promotes action depends on the child's developmental progress as covered by Vygotsky's idea of ZPD. According to Valsiner (1987, p. 111), the adult offers the child being assisted "just that level of intervention which is necessary to get the child over his current difficulties." At every developmental period, the ZFM/ZPA complex organizes the child-environment relationship while the ZPD organizes the child's psychological development on the ontogenetic plane. Thus the zone concept assists children in interweaving everyday concepts with scientific concepts.

The developmental potential reflected as the difference between everyday concepts and scientific concepts refers to what Vygotsky called the zone of proximal development (ZPD). The ZPD taps the psychological functions which are still in the developmental process and which could be overlooked unless the focus centers on assistance with a more capable adult (Kozulin, 1990). Accordingly (Kozulin, 1990):

> Vygotsky suggested that the recognition of the effect of "scientific" concept learning on mental development may revive the original spirit of formal

> discipline: the systematic learning of scientific concepts in one field translates into developmental changes in the direction of greater abstraction of thought and greater awareness of and control over one's own actions. These changes, in their turn, support learning in other fields. (p. 171)

However, such learning processes do not occur automatically, for formal learning and mental development possess different 'rhythms' depending on the individual student (Kozulin, 1990). For example, a student's learning about photosynthesis does not necessarily translate into a greater understanding of biology.

The relationship between learning and mental development shows no uniform pattern (Kozulin, 1990):

> For each discipline and each student the interacting curves of learning and development need to be plotted individually. Special attention should be paid to so-called sensitive periods during which even a limited investment in learning produces an abundant return in mental development. One example would be the "explosion" of verbal awareness in children who are taught to write between four and a half and five years of age. (p. 171)

Depending on the child, then, the ZPD can be realized at a higher level when taking advantage of peak periods. Another such example could be a teacher's taking time to teach about a hurricane whenever a hurricane actually strikes an area, or teaching about ecological experiments in space following a newscast on some space phenomena.

An interesting development in American psychology pertains to "the recent rediscovery of the problem of scientific versus everyday concepts, appearing now as the problem of restructuring the child's knowledge from that of ‘novice’ to that of ‘expert’”(Kozulin, 1990, p. 172). Carey (1985) authored a detailed monograph on the restructuring problem, but did not refer to Vygotsky. Carey's two points of departure included the philosophy of science idea of theory change and Piagetian stage theory. She questioned children in the age range of four to ten about different plants and animals and taught the concepts of organs and physiological functions to determine if there is a statistical change in a child's concept of what is living or what is plant or animal. Conclusions indicated that older children developed an explanatory system abstracting physiological systems, which she called 'naive biology.' On the other hand, younger children continued to think of animals as behaving things in comparison to human behavior, a system she called 'naive psychology.' Thus questions about living organisms tend to be answered through comparison with human traits. The 'comparison-to-exemplar' system of reasoning may assist with the development of the Vygotskian typology of preconceptual thought, such as syncrets and complexes according to Kozulin (1990).

The 'structure of learning' involves processes characterized by an ordered, or structured sequence. Identifying the structure of learning processes draws from a variety of theoretical concepts, including a genetic growing system, a dynamic learning system, a productive learning activity, and task specific development (van Oers, 1996). Accordingly, learning is both culturally and socio-historically influenced, and learning processes develop through a social context, which is mediated by means of largely self-determined co-construction. The ZPD is related to action during activities and is a result of shared activity between the child and an adult or more capable peer.

Dynamic Nature of the ZPD

Interestingly, the ZPD is dynamic and shifts to a higher level as the child approaches an elevated state of conceptual understanding (Bodrova & Leong, 1996). As each progression in learning occurs, the child develops the capability to build toward learning additional and more complex concepts and skills. The ZPD varies from one child to another. and during different times of development of learning. Some children need assistance in one certain area more than in another. Even with assistance, some children still need prompts and modeling to learn certain skills and concepts. With assisted performance, the child continues to learn on a higher plane. What the child can learn with assisted performance today ultimately becomes what the child knows without assistance. Eventually, assistance is no longer needed. The child has then reached the ultimate level on the ZPD continuum.

Chapter 3

Methodology

The purpose of this cross age study was to investigate students' understanding of the interdependencies of seed dispersal, pollination, and food chains using a constructivist theoretical framework. The current literature does not reveal students' understanding of the importance of plant-animal interdependencies to survival. Therefore, specific research questions were developed to examine this important biological concept as follows:

1. What everyday concepts and what scientific concepts do students have pertaining to biological interdependency of pollination, food chains, and seed dispersal?
2. What patterns of student knowledge of interdependency in pollination, food chains, and seed dispersal are evident across grade levels?
3. How can results from the interviews be used to construct an understanding of a students' zone of proximal development (ZPD) with respect to the interdependency concepts of pollination, food chains, and seed dispersal?

Participants

Subjects interviewed in this study represented a convenience sample. The participants (N = 24) in this cross-age study consisted of six students selected from each of three grade levels: 3, 7, and 10, plus six college students. A qualitative study of this type typically involves no more than 25 students due the intensity of data collection through interviewing. The grade levels for the subjects were selected on the basis that the spacing would generate data from each school division, K-5, 6-8, 9-12, and college levels, a cross-age study for comparison purposes.

The pre-college participants were selected from a youth group in a community center that serves a rural school community and from a charter school in an urban area in the southeastern United States. The college students interviewed attended a large land grant university located in the same area. All students volunteered to participate in the study and were selected based on scheduling availability. Each student participant was interviewed according to the researcher-designed protocol, using the same questions in the same order.

Anonymity of the subjects was maintained throughout the study to protect the privacy of the participants and of the schools and college involved. A numbering scheme was used to identify student interviewees. For example, student interviewee number one in grade 7 was designated student 7-1; student interviewee number two in grade 7 was designated student 7-2, and student interviewee number three in grade 7 was designated student 7-3, with successive interviewees being designated 7-4, 7-5, and 7-6. Data from students in the other grade levels were coded similarly. College students were designated C-1 through C-6. The names of the schools were changed as well, using names to reflect the level, for example, Little Acorn Elementary, Maple Middle School, Pine Forest Secondary School, and Southern Oak University.

Methodological Framework

The methodological framework selected for this qualitative research study was phenomenology. By definition, a phenomenological study (Creswell, 1998) focuses on the experiences of individuals pertaining to a particular concept, called the phenomenon, in this study, everyday concepts versus scientific concepts on interdependency. The phenomenological method guided the research design, and the primary method of data collection was interviewing, appropriate for this study for several reasons. First of all, interviewing is the preferred method for phenomenological studies. Second, interviewing allows a one-on-one discourse, which is especially useful in science educational research to determine what students know or don't know. Third, interviewing allows the use of pictures to guide students' responses. In the phenomenological study, the researcher has extensive knowledge of the concept, and the subjects vary in their knowledge and experience of the concept or phenomenon selected for the research. Therefore, a knowledgeable researcher uses interviewing techniques including pictures to elicit responses from the subjects. By using a combination of methods, more "lenses" became available through which to view results (Morse, 1998).

In developing the interview questions, Spradley's (1979) interview protocol model was used which includes three main types of questions: descriptive, structural, and contrast. Descriptive questions require the subject simply to describe or explain some object or event. For example, "Explain methods of seed dispersal." In this study structural questions enabled the researcher to find out how the subject organized knowledge about a particular idea or concept. For example, "What would happen if all the pollinators died?" Structural questions can reveal the organization of a participant's knowledge. Contrast questions were asked to convey dimensions of meaning. An example of a contrast question is, "What is the difference between a producer and a consumer in a food chain?"

Each child makes sense of his or her own learning by using previous knowledge and understanding of the world. Because each child has a different reference frame, understanding the meaning of words differs among students at different cognitive levels. A child constructs meaning in responding to an interviewer's questions, and the interviewer must interpret underlying meanings. Therefore, the protocol was designed to elicit meaning by asking the same question in a variety of ways. Eventually, through multiple responses, children may reveal their understanding and interpretation. The qualitative method of phenomenology simply represented a means to journey from an idea framed by a theory to a collection and analysis of data to report the findings, as in this cross-age study.

Data Sources

Interviewing represented the major means of collecting data for this research study. Interviews were designed in consideration of the various ages of the students involved to establish equivalence for each grade level. The data were obtained through participant observation and in-depth interviewing, a naturalistic approach involving an interpretive understanding of students' experiences and formal instruction (Lincoln & Denzin, 1994). Point-in-time interviews were utilized in this cross-age study to evaluate the level of students' thinking and understanding in accordance to the grade. Pictures used in interviews helped students to recall information and to communicate their conceptual understanding. Pictures have been found to be especially helpful with younger students (Hulland & Munby, 1994). Pictures represent viewfinders that assist with interviewing by providing a means of active listening to invite more in-depth thinking and recall to keep the interview flowing (Bell, 1995).

The researcher audiotaped each interview using two tape recorders simultaneously in case one malfunctioned. The researcher used questions and active listening, as well as viewfinders, to direct each student's thinking and to channel each student's reasoning. For example, a verbal viewfinder could include the statement, "How did you reach that understanding?" Each student was interviewed once in a quiet area of a library at a time agreed upon by all parties. Interviews for all students lasted thirty to forty minutes, allowing time for students to organize card sorts for the third component of the study, food chains. All audiotapes were transcribed for analysis.

The cards used in the card sort consisted of plants and animals involved in two different food chains. The students were asked to group one set of cards at a time. Students were videotaped while arranging the card sorts. The interviewer tracked each participant's rearrangements of cards during the card sort process by recording notes on the order of the food chains.

Interview Protocol

The protocol for interviewing subjects included questions about seed dispersal, pollination, and food chains. For seed dispersal, the interviewer first showed the students a picture of a dandelion flower growing alone, then asked question one and waited for the student to respond. Questions 2-5 followed. Next, the interviewer showed students a dandelion seedpod and asked the remaining questions in order beginning with question 6. The following questions were included in the seed dispersal part of the research protocol:

1. How do you think the lone dandelion plant happened to grow here?
2. Have you ever walked through some weeds and have seeds stick to your socks or jeans?
3. Have you ever seen seeds stick to an animal's fur?
4. Why do you think the seeds are made so they will stick to humans or animals?
5. Is there any benefit for the seeds?
6. Do you know what a dandelion seedpod is?
7. Have you ever picked a dandelion seedpod and blown on it? What happened?
8. What is each of the little cottony structures that blow in the wind?
9. Have you ever seen yellow powder on the ground or on your parents' cars?
10. What is the yellow powder?
11. Where was the yellow powder before it blew or fell on the cars?
12. What is the use of the pollen?
13. Have you ever seen seeds in water?
14. Where does the water take the seeds?
15. Do you know what is meant by seed dispersal?

For the pollination component of the protocol, each subject was shown a series of related photographs of flowers and pollinators and asked the pollination questions in the same order shown in the protocol as follows:

1. Why is the honeybee buzzing around the flowers?
2. What attracts the honeybee to the flowers?
3. Does the honeybee help the flower?
4. Does the flower help the honeybee in any way?
5. What is the hummingbird doing?
6. What about the bumblebee?
7. Does the bumblebee help the flower?
8. Does the flower help the bumblebee?
9. Look at the butterfly. Have you ever seen butterflies in your yard?
10. Where do you usually see butterflies? What are the butterflies usually doing?
11. Do you usually see butterflies in the sun or in the shade?
12. What kind of flowers do butterflies like?
13. Do butterflies help the flowers?
14. Do the flowers help the butterflies in any way?
15. Do you know of any other insects that like to fly around flowers?
16. Do you think other insects may help flowers?
17. What are some other insects that may benefit flowers?
18. Do you know what nectar is?
19. Where is nectar in flowers?
20. Have you ever heard of pollen?
21. Where is pollen in flowers?
22. Why is pollen important to the flower?
23. Can flowers and insects continue to live without each other?
24. What would happen if all the honeybees died?
25. What would happen if all the flowers died?
26. Do you know what pollination is?

For the third component of the research protocol, food chains, the researcher used both an interview protocol and card sorts. First, the researcher showed the participants a photograph of a rabbit and asked what the rabbit ate. Pictures of wolves and foxes were shown, and the students were asked a series of questions in the food chain protocol as follows:

1. What do you think is happening?
2. What do you think the rabbit will eat?
3. Suppose no grass is growing. What else might the rabbit eat?
4. Suppose all the plants died. What would happen to the rabbit?
5. Note the picture of the fox. What does a fox eat?

6. Suppose all the rabbits went to another place or died. What would the fox eat?
7. Note the picture of the wolf? What does a wolf eat?
8. Suppose there are no foxes or rabbits. What would the wolf do?
9. Can you think of another food chain?
10. What is a food chain?

The card sort for the first food chain included the same producers and consumers as in the interview, grass, rabbits, foxes, and wolves. Students were instructed to arrange one set of cards at a time. The second card sort involved elements of a food web and included cherries, insects, birds, and hawks. As with the first card sort, students were instructed to group the cards according to "what eats what". The interviewer tracked each participant's rearrangement of cards during the card sort process.

This use of card sorts results in an equivalence protocol, that is, an equal question for all participants. A card sort can consist of a group of cards with words or pictures or both. The food chain card sorts used for this study consisted of words only, for the researcher had previously showed pictures during the food chain protocol.

Data Analysis

The methodological framework guided the data analysis. When asked questions during an interview, students do not simply respond from an empty vessel. Throughout life in a world of experiences, observations, and formal instruction, each student has constructed a knowledge base that can be accessed on demand to generate responses to challenging questions. Data analysis involved a systematic process that began with planning the research, impacted the actual data collection in the field, and provided the framework for emerging themes (Bogdan & Biklen, 1992). Data analysis for the phenomenological study involved a method for reduction of data by categorizing, analyzing specific statements and patterns, followed by a search for every possible meaning.

Analysis began with categorizing and organizing the raw data, analyzing statements for meaning, establishing criteria for analysis and situating the analysis within the theoretical framework. Interviews were categorized into seed dispersal, pollination, and food chains, the three areas of research and were examined by and across grade levels.

A constant comparison method of analysis, developed by Glaser and Strauss (1967), a process of data analysis that combines inductive category coding with the simultaneous comparison of all observed social incidents was employed. Comparison of social phenomena leads to generation of hypotheses as incidents are constantly compared with previous events and new events or relationships. Basically, the constant comparative method for this study involved sorting data units into provisional categories, which look alike but have only implied, or tacit understanding. As the provisional categories increase to a certain number of unit cards, the researcher wrote a propositional statement that served as the basis for inclusive and exclusive decisions as with the food chain concept (Lincoln & Guba, 1985). In this study, data categories were constantly sorted and compared, following the constant comparative method. The rule was further amended as additional categories were considered and until a specific conclusion was reached about each subject's level of development. Specific details of the analytic procedure follow.

Data analysis for this study involved intensive interview reviewing. First of all, the researcher read through all 24 transcriptions. The transcriptions were reread according to concept across grade levels. Next, the researcher focused on tabulating individual responses to seed dispersal, starting with grade three and continuing with each grade until completing responses for each grade. The researcher then generated data tables listing every response to every question by each student in the four grade levels (See Appendix). Graphs were generated illustrating the number and types of responses pertaining to each major concept in seed dispersal (See Appendix). The researcher followed the same procedure for the responses to pollination questions. For the food chain concept, a review of responses by grade level initially revealed no difference. Therefore, no graphs or tables were generated for this round of data analysis.

Following tabulation and graphing of data, the researcher generated data analysis tables for each interdependency. Three parts compose the table for each grade level and each concept: everyday concepts, transition/ZPD/mediation according to Vygotsky, and scientific concepts. The specific rationale for using the three headings in the tables was to categorize and analyze students' experiences by analyzing the interweaving of everyday concepts, mediation, and scientific concepts to determine students' level of understanding of scientific concepts for each interdependency. Word meanings consistent with accepted science knowledge tend to evolve from children's intertwining of everyday and scientific concepts or constructs, just as a vine intertwines around a twig or a tree (West & Pines, 1985). Vygotsky's theory is best defined in terms of both teaching and learning as a unifying process to construct knowledge, not a separation of the two processes. Furthermore, the students' everyday concepts and scientific concepts evolved in a complementary process through the student's zone of proximal development.

First of all, for each student the everyday experiences that emerged from the interview were identified and listed. These responses represented what the students already knew and could immediately recall and re-construct upon initial questioning. Therefore, responses identified as everyday concepts represent students' initial responses to each question without mediation or probing.

Responses identified as mediation/transition/ZPD, occurred as a result of mediation through relevant follow-up questions. Transition from everyday concepts to scientific concepts within 'zones' of proximal development further revealed students' understanding of the interdependency concepts. In other words, the researcher asked probing questions to try to elicit understanding that the student may not have immediately recalled, but could re-construct with assistance, depending on the ZPD. Identifying and listing everyday experiences that emerged spontaneously and with mediation is a good way to organize and analyze interview responses in terms of where students are in the continuum of developing a scientific concept because everyday concepts lead to the development of scientific concepts.

Scientific or formal concepts that students specifically recalled and reconstructed or stated during the interview, were identified and listed, then level of development was summarized in one of three ways. "None evidenced," indicates that the student's responses did not provide any evidence of true conceptual understanding. "Developing" means that the student described one major element of the concept, indicating a beginning scientific understanding. If a student described at least two major elements of the concept with or without mediation then the student showed "developed" understanding at the scientific or formal level. Elements of understanding were identified by the researcher prior to this phase of analysis. These elements are listed in the first table of each of the three sections, seed dispersal, pollination and food chains, in the results chapter. Although more than two elements are listed for each concept any combination of two or more are sufficient to provide evidence of understanding. One should keep in mind, as data analysis tables are reviewed in the results section, that the level of scientific development was determined not only by the responses listed in the first two columns but had to be interpreted in context of the interview.

This means that even if a mediated response appears to infer conceptual development, unless there was additional evidence in the context of the interview that the student had gained insight through mediation, conceptual development was not indicated.

The researcher also identified students' use of correct terminology, such as dispersal as evidence of scientific understanding. The researcher also accepted synonyms as evidence of scientific understanding of scientific concepts. For example, some students that showed a developing concept in seed dispersal used synonyms for dispersal, such as carried, spreads, spreading, scatters, transports, disperses, "dispersement," or that some agent of dispersal "takes" seeds to places. Several rounds of reviewing, interpreting and categorizing responses took place as the researcher looked for sense making, imagery, and memory from students' responses to determine the students' experience of the phenomenon. Since children across grade levels vary in their sense making of the world depending on experience and instruction, that is, as a result of their zone of proximal development, the researcher also considered responses and applied evidence from the literature to interpret the responses. By comparing students' responses to accepted science knowledge, the researcher established what Lythcott and Duschl (1990) called 'goodness of fit.' Interpretation of the interview responses in the child's frame of reference leads to improved reliability and validity.

The third concept, food chains also employed card sorts as another data source for examining students' understanding. Therefore these results were used in conjunction with interview responses to determine students' level of understanding about food chain. To determine conceptual understanding on food chains, card sort data were linked to food chain interview data. Card sort data include three headings: food chain 1, food chain 2A, and food chain 2B. Food chain 1 was a simple food chain and the same one used in the interview data.

Food chain 2B indicated that the students sorted the cards to show the food web characteristic, with producer on the bottom, first and/or second order consumers on line 2 and third order consumer on line 3. Some students arranged the card sort for food chain 2 by both methods.

In analyzing conceptual understanding for food chains, the researcher used evidence of scientific concepts from interviews plus the food chain card sorts by both methods to state the level of understanding. None evidenced indicated that the students showed everyday experiences only and arranged the cards in a linear fashion only. Developing showed that the student arranged the cards for food chain 1 in the proper producer-consumer level and the cards for food chain 2 by either one or both methods and showed at least one element of the scientific concept during the interviewing. The researcher included arranging card sort 1 in order, arranging card sort 2 by both methods, and at least 2 elements of scientific concepts from interviews to indicate developed understanding.

The interview data and analyses were reviewed by a second researcher and interpretations of level of scientific understanding were negotiated until agreement was reached. A third researcher with no connection to the project reviewed a sample of interview data and categorized responses as everyday or mediated. Inter-rater reliability was calculated as 0.71, which is within the accepted range for interview data.

A discussion of the data collected and an interpretation of the data included supporting quotes from participant responses. Inferential statements pertaining to each category were made and supported by data and researcher comments on theory and review of the literature. A general, all-encompassing statement referring to students' conceptual understanding of everyday concepts and scientific concepts as gleaned from the data was then presented. The data collected were compared across grade levels to evaluate similar everyday and scientific concepts held by the participants and to determine their zone of proximal development.

Chapter 4

Results

Chapter four presents the results of student interviews on the interdependency of plants and animals in three sections representing the major concepts: seed dispersal, pollination, and food chains. A table listing potential, relevant responses to the interview questions for everyday and scientific concepts introduces each of these three sections. A description of the results for each grade level follows. This description includes a data table for each grade level indicating each student's everyday experiences, transition as mediation/ZPD, and scientific conceptual understanding, which were constructed as described in the methodology. A summary of the analysis, representative quotes, and discussion of variation among students' responses accompany this table for each grade level. To illustrate cross-age differences in development, a summary table and description of the differences found ends each section. This chapter concludes with a summary of the findings for each of the three research questions.

Seed Dispersal

To assist with the analysis process a list of everyday concepts and scientific concepts that could come as responses from interview questions was generated for seed dispersal and is shown in Table 1.   Everyday concepts are those that students could identify as having experienced in response to questions in the interview protocol related to this topic. Component ideas related to scientific understanding of seed dispersal are listed in the second column. Following this table responses to interview questions related to seed dispersal are analyzed by grade level.

Table 1

Everyday Concepts and Scientific Concepts on Seed Dispersal

Everyday Concepts (Experiences)	Scientific Concepts (Components of Seed Dispersal)
•Plants grow from seeds.	•Seeds are dispersed by different methods, people, animals, wind, and water, and eventually land in various places to grow.
•Seeds stick to humans and animals.	•Seeds have adaptations for dispersal (sticky, barbs, prickles, wings, feathery).
•Wind (Seeds in air).	•Seeds are interdependent with their dispersing agents.
•Water (Seeds in stream, river).	•Seed dispersal is the scattering, spreading, or transporting of seeds.

Grade 3- Seed Dispersal Response Analysis

Table 2 shows responses of students in grade 3. Note that all students in grade 3 have had extensive everyday experiences with seed dispersal. Of the grade 3 students, 5 out of 6 showed no evidence of understanding seed dispersal on the scientific level, indicating that the concept was beyond the students' zones of proximal development. One of the 6 students, student 3-4, demonstrated a developing understanding at the scientific or formal level, as indicated by the observation that not mowing grass results in more dandelion flowering. Mediation was necessary to probe students for generating additional responses not immediately recalled and reconstructed from their repertoire of knowledge on seed dispersal and these responses are shown in column 2.

All students in grade 3 showed varied everyday experiences in the understanding of seed dispersal. For example, student 3-1 had some everyday experiences with seed dispersal phenomena as to how seeds travel, but had no concept of why. The student's responses indicated that seeds "fall off," "go everywhere," or "travel around in circles," without a connection to a method of seed dispersal. The student stated that the maple seed traveled around in circles because it is a seed. Understanding seed dispersal on a scientific level was simply not within this student's zone of proximal development as defined by Vygotsky. That is, even with attempted mediation, the student did not recognize seed dispersal. For example, when asked what was done with seeds attached to clothing, the student responded, "Threw it in the trash." A seed sticking for the purpose of dispersal was simply not in the student's zone of proximal development. Student 3-1 responses showed no evidence of true conceptual understanding at the scientific or formal level.

Table 2

<u>Summary of Grade 3 Responses on the Methods of Seed Dispersal</u>

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Understanding*
3-1	• Plants grow from seeds • Seeds stick to humans or animals • Wind (Seeds in air) • Seeds in water	• Seeds fall off as people/ animals move around • Seeds carried to other places by water can grow	□None evidenced
3-2	• Plants grow from seeds- somebody dropped seed • Seeds stick to dogs • Wind (Seeds in air) • Seeds in water	•Seeds fall off as animals move around •Seeds blow, fall to ground and grow • Seeds carried by water to other places can grow.	□None evidenced
3-3	• Plants grow from seeds • Somebody planted seed • Seeds stick to humans and animals •Wind (Seeds in air)		□None evidenced
3-4	• Seed planted or grows by itself • Wind (Seeds in air)	•Seeds stick to people and animals • Maple seeds float	□Developing concept •Not mowing allows dandelion seeds to spread
3-5	• Plants grow from seeds • Seeds stick to dog's fur • Wind (Seeds in air)	• Seeds moved by wind and animals • Water can take seeds everywhere	□None evidenced
3-6	• Plants grow from seeds- planted by people • Seeds stick to people • Wind (Seeds in air)	•Seeds get to different places when humans and animals move around	□None evidenced

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
= Scientific concepts revealed during interviewing/mediation

Everyday experiences can also provide a roadblock to further understanding, as shown by the following excerpt. Preceding the interview, student 3-3 stated with excitement that her mother had a garden. Note responses to the interview questions.

> Interviewer: How do you think the dandelion plant got to the location in the grass?
> 3-3: Somebody had a garden.
> Interviewer: So how do you think the seed got there to grow?
> 3-3: Probably someone had wanted to grow a garden, one flower that was their favorite and planted it there.
> Interviewer: Do you think the wind could have blown it there?
> 3-3: Somebody probably planted it there.

Regardless of the number of ways the question was asked, the student responded each time that the seed got to the location because somebody had a garden and planted the seed. Further questioning elicited the following responses:

> Interviewer: Have you ever walked through weeds and had anything like these stick to your clothing? (shown a shirt with beggar's lice -stick-like seeds with barbs)
> 3-3: It is something like a little stick and it is like when I walk through the grass it attaches to my sock.
> Interviewer: Have you ever seen seeds stick to an animal's fur?
> 3-3: No.
> Interviewer: You haven't seen a seed stick maybe to a dog?
> 3-3: Yes.
> Interviewer: Why do seeds stick to your socks or to an animal's fur?
> 3-3: At the bottom it probably has sticky stuff.
> Interviewer: Why do you think the seeds are made so they will stick to humans or animals?
> 3-3: *No response*.

Note in the above responses that the student had no idea of why seeds attach to humans or animals, cause and effect, that humans and animals represent methods of seeds dispersal. Why seeds attach is simply not within her zone of proximal development, as Vygotsky would explain. Probing questions with extensive mediation as to what happens to seeds that stick to humans and animals eventually led the student to state that seeds would end up in the dirt, but would not grow. Following are student 3-3 responses when shown a photograph of a dandelion seedpod:

Interviewer: This is a dandelion seedpod.
3-3: You blow it.
Interviewer: All right, you blow on it.
3-3: And the white stuff comes out.
Interviewer: Do you know what the white stuff is?
3-3: No, but I have seen some fly in the air. I seen, a big one that looked like a spider, and I tried to catch it and make a wish, but I didn't catch it.

As the interview indicates, student 3-3 has no idea that dandelion seeds are designed and adapted for wind dispersal. No scientific or formal level of understanding is evidenced.

Student 3-4 showed varying everyday experiences and a developing conceptual understanding at the scientific or formal level as indicated by the following:

Interviewer: How do you think the dandelion grew in that particular spot?
3-4: You put seeds and then it starts growing if you water it or it rains.
Interviewer: Do you know why seeds will stick to your socks or jeans?
3-4: Because they are sticky.
Interviewer: Have you ever blown on a dandelion seedpod?
3-4: Yes.
Interviewer: What happened?
3-4: It goes into different places, then you can't find it.
Interviewer: Whenever you have these seeds go everywhere, you might just have dandelion flowers everywhere like this. Right?
3-4: Yes.
Interviewer: Then, if you have dandelion flowers everywhere, you are going to get a lot more seedpods everywhere.
3-4: Then it will keep growing if you quit mowing them.

Analysis of student 3-4 responses demonstrated that the student had numerous everyday experiences with methods of seed dispersal. Continued questioning led the student to re-construct additional experiences involving scattering of seeds. The main response that indicated a possible developing level of understanding on the scientific or formal level is the response that dandelion flowers would "keep growing if you quit mowing them" as indicated in the interview above. Obviously, the student had observed that if dandelion flowers are no longer mowed, then seedpods will keep developing and continue to be scattered by the wind to land in different places to continue to grow.

Grade 7- Seed Dispersal Response Analysis

Grade 7 responses (Table 3), evidenced that all students had extensive everyday experiences with seed dispersal. Mediation elicited further responses to seed dispersal within the students' zones of proximal development. Only 1 out of 6 students in grade 7 showed a developed scientific conceptual understanding. Students, 7-1 and 7-2, showed a developing understanding; three students demonstrated no evidence of scientific understanding.

An analysis of seed dispersal responses by grade 7 showed some advancement in understanding beyond grade 3. Student 7-1 promptly answered all questions accurately on seed dispersal and demonstrated numerous everyday experiences. The student knew that seeds traveled to other locations to grow.

> Interviewer: Why do you think seeds stick on animals or fur or humans?
> 7-1: To help the plants move; more places to grow.

Student 7-3 had some everyday experiences with seed dispersal, but showed no real evidence of understanding at the scientific level. First of all, the student knew the dandelion flower grew from seeds, but could not generate a response as to how the seed got to the location. The student had had seeds stick to clothing, but had not observed seeds sticking to animal fur. Furthermore, the student could not explain why seeds might stick to clothing or animal's fur. Upon probing, the student finally stated that humans and animals move around, but could not explain that the seeds would eventually fall to the ground and grow.

> Interviewer: Have you ever walked through some weeds and had something stick to your socks or jeans?
> 7-3: Yes.
> Interviewer: Have you ever seen seeds stick to an animal's fur?
> 7-3: No.

Interviewer: Not any animal? Not even a dog?
7-3: No.
Interviewer: Why do you think seeds stick to your socks or jeans or to animal's fur?
7-3: I don't know.
Interviewer: If you got seeds on your sock, most likely you would do what?
7-3: Get it off.
Interviewer: And what would you do with them?
7-3: I would probably throw them in the trashcan.
Interviewer: Have you ever seen dandelion seedpods in your yard?
7-3: Yes. We blow them.

The statement that student 7-3 would throw the seeds in the trashcan is an indication that seed dispersal by humans was simply not in the zone of proximal development. Grade 7 responses are presented in Table 3 below.

Table 3

Summary of Grade 7 Responses on the Methods of Seed Dispersal

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
7-1	•Plants grow from seeds •Seeds stick to humans & animals •Wind (Seeds in air) •Seeds in water	• Seeds stick to people & animals; helps the plants to move to more places to grow •Seeds taken to other places by water can grow	□Developing Seeds have adaptations-sticking-to move to more places to grow
7-2	•Plants grow from seeds •Stick to humans or animals •Wind (Seeds in air) •Water-takes seeds to soil	•Wind blew seeds to area •Seeds are sticky so they can get around and grow somewhere else	□Developing •Seeds have adaptations-sticky- to get to other places to grow
7-3	•Plants grow from seeds •Wind (Seeds in air) •Seeds in water		□None evidenced
7-4	•Plants grow from seeds •Seeds stick to humans and animals so are transported •Wind (Seeds in air) •Seeds in water	•Birds and wind spread seeds •Animals spread seeds •Seeds are sticky so they can travel to other places to grow	□Developed •Seeds are spread by wind, people, animals, to other places to grow Seeds adaptations-sticky-to move to grow in other places
7-5	•Plants grow from seeds-people agents •Stick to humans or animals •Wind (Seeds in air) •Seeds in water	•Seeds stick to clothing because of static; sticky structure	□None evidenced
7-6	•Plants grow from seeds-wind and people agents •Stick to humans or animals •Wind (Seeds in air)	•Water takes seeds to the banks of streams	□None evidenced

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
= Scientific concepts revealed during interviewing/mediation

Student 7-4 showed conceptual understanding at the scientific or formal level. The two responses that showed scientific understanding were that seeds spread the dandelion plant and that the seed could have been transported by the wind or by a bird. Both “spread” and “transported” are synonyms for dispersal. Furthermore, student 7-4 spontaneously identified two methods of seed dispersal to explain how the dandelion happened to grow in the grass.

Interviewer: Can you tell me how did the plant get here?
7-4: Spread by seeds.
Interviewer: Are there any other ways it could have gotten there?
7-4: A bird.
Interviewer: Any other way?
7-4: The wind.
Interviewer: Have you ever walked through some weeds and had something stick to your socks or jeans?
7-4: Yes.
Interviewer: Why do you think seeds stick to your socks or jeans or to an animal's fur?
7-4: Because they stick to your clothes so they can get <u>transported</u> to places and they can grow.
Interviewer: And why do you think the seeds are made so they stick to humans or animals?
7-4: So they can travel to different places and grow.

<u>Grade 10 - Seed Dispersal Response Analysis</u>

All students in grade 10 indicated varied everyday experiences with seed dispersal. Over all responses showed no significant advancement beyond grade 7 responses (See Table 4). With additional questions, some students were able to give a cause and effect relationship. One student, student 10-4, demonstrated a developed understanding at the scientific or formal level.

Student 10-1 had some everyday experiences with seed dispersal. For example, the student had seeds stick to clothing and had seen seeds stick to an animal's fur, that "animals pick up seeds, and they go from place to place. " Mediation led the student to respond that seeds fall off when humans and animals move around. However, the student did not respond in any way to indicate understanding on the scientific level beyond acknowledgement that seeds could be transported.

Table 4

Summary of Grade 10 Responses on the Methods of Seed Dispersal

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
10-1	•Plants grow from seeds •Seeds stick to humans or animals •Wind (Seeds in air)	•Seeds carried by wind or animal •Seeds stick then fall off as humans and animals move around •Water transports seeds	□Developing •Seeds have adaptations-stick to move from place to place
10-2	•Plants grow from seeds •Seeds stick to humans or animals •Wind (Seeds in air) •Seeds float in water	•Seeds fall off as humans and animals move around •Seeds spread and re-grow •Water takes seeds to land to grow	□Developing Seeds spread and grow elsewhere
10-3	•Plants grow from seeds •Seeds stick to humans or animals •Wind (Seeds in air) •Seeds in water	•Seeds fall off as humans and animals move around • Water takes seeds under ground	□None evidenced
10-4	•Plants grow from seeds-through pollination •Seeds stick to humans or animals •Wind (Seeds in air) •Water takes seeds to land	•Wind moves seeds •Seeds fall off/spread around as animals move •Blowing on dandelion is dispersal by air/wind •Seed dispersal-scatters	□Developed • Seeds falling in different places is spreading of seeds •Wind spreads seeds •Pollination results in seed growth
10-5	•Plants grow from seeds-seeds planted by people •Stick to animals •Wind (Seeds in air) •Seeds in water	•Wind moves seeds •Seeds fall off humans and animals and grow in another place	□None evidenced
10-6	•Plants grow from seeds-people grew •Seeds stick to humans	•Seeds fall off as humans and animals move	□None evidenced

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
= Scientific concepts revealed during interviewing/mediation

Student 10-3 could not respond how the dandelion seed grew in the lone location except to state that someone planted the seed. Seed dispersal by any other means was not within the zone of proximal development for student 10-3. The student knew that seeds were adapted to stick to humans and animals, yet required mediation to respond that seeds fall to the ground when humans and animals move around. The student's everyday experiences were not connected to the concept of seed dispersal.

Student 10-4 was the only tenth grade student who demonstrated conceptual understanding at the scientific or formal level. Student 10-4 responded as follows:

> Interviewer: Do humans and animals move around or do they stay still?
> 10-4: They move around.
> Interviewer: So, what happens to the seeds when they move around?
> 10-4: They fall off.
> Interviewer: And they fall in different places. Then what happens?
> 10-4: That's like they are spreading.
> Interviewer: Have you ever picked a dandelion seedpod and blew on it?
> 10-4: Yes
> Interviewer: What happened when you blew on it?
> 10-4: They spread around.

Note that student 10-4 used the term "spreading," a synonym for dispersal, indicating scientific understanding, then used the term spread as the interview continued to explain that seeds move around, a further indication of scientific or formal understanding.

College Students - Seed Dispersal Response Analysis

Significant advancements in understanding of seed dispersal were evidenced at the college level. All students demonstrated varied everyday experiences, and most importantly, all students exhibited understanding at the scientific or formal level. Responses that indicated scientific understanding included the following components:

- Plants grow as a result of seed dispersal.
- Seeds stick to humans and animals and spread.
- Blow on seedpod and seeds spread or disperse by wind.
- Seed dispersal methods are by wind, water, animals, and people.

Table 5 summarizes seed dispersal responses by college students.

Table 5

<u>Summary of College Student Responses on Methods of Seed Dispersal</u>

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
C-1	•Plants grow from seeds- by seed dispersal •Stick to humans and animals; spread •Wind (Seeds in air) •Seeds in water	•Seed dispersal •Seeds stick to humans and animals-spread miles away •Water takes seeds to sandbars	□Developed •Seed <u>dispersal</u> by wind, water, animals, people Seeds have adaptation for spreading-sticking
C-2	•Plants grow from seeds •Stick to humans and animals •Wind (Seeds in air) •Seeds in water-places	•Wind, animals, insects, bees carry seeds • Seeds stick for transport and reproduction •Barbs and cockleburs are for protection	□Developed •Seed dispersal/transport by wind, water, animals, people Seeds have adaptation for transport-sticking
C-3	•Plants grow from seeds- •Stick to humans •Wind (Seeds in air) •Seeds maybe in water	•Wind, birds carry seeds •Seeds stick to humans; spread	□Developed •Seed dispersal/spreading by people, wind, animals Seeds have adaptation for spreading-sticking
C-4	•Plants grow from seeds •Stick to humans or animals-spread •Wind (Seeds in air) •Water takes seeds to land	•Seeds stick to humans and animals; spread •Wind spreads seeds	□Developed •Seed dispersal-spreading and dispersement by wind, water, animals, people Seeds have adaptations for spreading-sticking
C-5	•Plants grow from seeds •Stick to humans or animals •Wind (Seeds in air) •Water-seeds to land	•Wind and animals spread seeds •Seeds stick to spread or disperse; survival •Dispersal by wind	□Developed •Seed dispersal, disperse, spread by wind, water, animals, people Seeds have adaptations for spreading-sticking
C-6	•Plants grow from seeds- wind, human, or animal •Stick to humans/animals •Wind (Seeds in air) •Water-takes seeds to land	•Wind, people, and animals spread seeds •Stick for dispersement	□Developed •Seed dispersal; spread out, dispersement by wind, water, animals, people Seeds have adaptations for dispersal-sticking

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
= Scientific concepts revealed during interviewing/mediation

Student C-1 interview responses revealed understanding at the scientific or formal level. Note the use of the term seed dispersal early in the interview.

Interviewer: How did the plant get there?

C-1: Seed dispersal.
Interviewer: What kind of seed dispersal?
C-1: Maybe other plants and other seeds getting spread around—reproduction.
Interviewer: What are other ways seeds are spread?
C-1: By humans and animals.
Interviewer: Why do you think seeds stick to an animal's fur or to your socks or jeans?
C-1: So in that way they can increase the plant and flower production.
Interviewer: In what way would the seeds get to more locations?
C-1: By spreading.
Interviewer: Some seeds have barbs that stick to people's clothing or to an animal's fur. How does that help the plant?
C-1: If they get stuck to an animal or human, they're going to different locations maybe miles away so they canspread.
Interviewer: Do you know what this is?
C-1: A dandelion seedpod. When the flower matured, it developed into a seedpod.
Interviewer: Have you ever picked a dandelion seedpod and blown on it?
C-1: Yes.
Interviewer: What happened?
C-1: It all gets into a million different pieces.
Interviewer: Do you know what the cottony white structures do?
C-1: They shoot out and spread and fly away.

Clearly student C-1 had numerous everyday experiences with seed dispersal. The student noted causes and effect, that if seeds attach to clothing or fur or blow in the wind, the effect will be that seeds will be spread farther.

Student C-5 showed understanding at the scientific or formal level by describing seed dispersal and indicating the biological benefit.

Interviewer: Do you know how the flower happened to grow there?
C-5: They blow in the wind and then fall on the ground.
Interviewer: Is there any other way it could have gotten there?
C-5: If it got picked up by an animal or something. Like on the fur, if it brushed by one and fell off later.
Interviewer: And why do these seeds stick to your socks or jeans or to an animal's fur?
C-5: So that it can disperse and get dropped off later somewhere else and grow.
Interviewer: What advantage is that to the plant?
C-5: Just growth and spreading out.

Student C-5 had numerous everyday experiences with seed dispersal. Responses to interview questions demonstrated that if seeds stick to humans or animals, the effect was that the seeds fell off and grew in another place. Note that student C-5 also used the term "disperse," further indicating that the concept of seed dispersal is within the students' zone of proximal development.

Cross-age Analysis

The development of scientific concepts was the focus of this study. Therefore, the progression of students' conceptual development across grade levels was examined and is illustrated in Table 6.

Table 6

Summary of Students' Conceptual Understanding of Seed Dispersal Across Grade Levels

Grade	Everyday Conceptual Understanding*	Transition Mediation/ZPD**	Scientific Conceptual Development***
3	6	5	5/1/0
7	6	5	3/2/1
10	6	6	3/2/1
College	6	6	0/0/6

*Everyday Conceptual Understanding by Number: Number with Everyday Understanding
**Transition/Mediation/ZPD: Number Revealing Additional Responses with Mediation
***Scientific Conceptual Development by Number: None evidenced/Developing/Developed

No student in grade 3, only one student each in grades 7 and 10, and all college students demonstrated development from everyday to scientific conceptual understanding on seed dispersal. Although some college students lacked recent experience in formal instruction of the concept of seed dispersal, their conceptual understanding at the scientific or formal level was overwhelmingly evident. One student in grade 3 and 2 students each in grades 7 and 10 showed a developing understanding toward scientific concepts. All students in the four grade levels showed varied everyday conceptual understanding. Five out of 6 students in grade 3 and 7 and all students in grades 10 and college revealed further understanding with mediation. Mediation did not necessarily result in indicating development toward scientific understanding. Mediation simply served to assist students in re-constructing their prior knowledge.

Pollination

Pollination represents the second interdependency concept. To assist with analysis, Table 7 was generated and represents potential everyday concepts and scientific concepts on pollination that could emerge from interview responses. Everyday experiences are listed in the first column and concepts of pollination are listed in the second column. Following table 7, concepts about pollination are examined by grade level beginning with grade 3.

Table 7

Table of Potential Everyday and Scientific Concepts on Pollination

Everyday Concepts (Experiences)	Scientific Concepts (Components of Pollination)
•Flowers attract honeybees, hummingbirds, bumblebees, butterflies, and other insects.	•Honeybees, hummingbirds, bumblebees, butterflies, and insects are pollinators attracted by color, nectar, and fragrance.
•Flowers provide food (honey)* for honeybees, hummingbirds, bumblebees, and butterflies.	•Food provided by flowers for pollinators includes nectar and pollen (sometimes given to developing insects for food).
• Pollinators gets pollen on body parts; take to other flowers	•Pollination is the transfer of pollen from one flower to another.
•Flowers and pollinators cannot live without each other	•Flowers and pollinators are interdependent; if one type of pollinator dies others can take over.

*Honey is used as a synonym for nectar as an everyday concept.

Grade 3 - Pollination Response Analysis

Table 8 consists of grade 3 responses to the pollination protocol.

Table 8

Summary of Grade 3 Student Responses on Pollination

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
3-1	•Honeybees attracted to flowers for honey •Flowers and honeybees cannot live without each other	•Yellow dust is pollen; pollen in middle of flower •No honeybees without flowers; no flowers without honeybees	□None evidenced
3-2	•Honeybees/pollinators are attracted to flowers to get honey	•If honeybees died, flowers could die •Pollen by hummingbirds and bumblebees •Pollination is pollen	□Developing •Pollination is pollen
3-3	•Honeybees/pollinators get pollen and honey •Flower has yellow pollen	•Pollinators get nectar •Yellow dust is pollen •Pollen in middle of flower	□Developing •Pollinators obtain nectar, and pollen from flowers
3-4	•Flowers attract pollinators •Honeybees/pollinators drink the honey	•Nectar is far back in the flower •Pollinators would die if flowers died	□None evidenced
3-5	•Flowers attract pollinators •Honeybees get honey from flowers •Yellow stuff attracts honeybees to flowers	•Hummingbirds, bumblebees, and butterflies look for food in flowers • Nectar and pollen are in middle of flower	□None evidenced
3-6	•Flowers attract pollinators •Honeybees /pollinators get honey from flowers •If flowers died, honeybees would have to eat bugs	•Pollen is yellow	□None evidenced

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
= Scientific concepts revealed during interviewing/mediation

Note that grade 3 students have had a number of everyday experiences with flowers and pollinators and that mediation revealed some additional everyday concepts. Interestingly, the only scientific concept grade 3 students understand is that honeybees and other pollinators get food from flowers in the form of honey. Note that student 3-3 indicated that honeybees obtain pollen and nectar in addition to honey from flowers.

Interviewer: Why do you think the honeybee is on the flower?
3-3: Because the honey flower has yellow stuff.
Interviewer: What is the yellow stuff?
3-3: Pollen.
Interviewer: What do you think attracts a honeybee to a flower?
3-3: Because it is yellow.
Interviewer: What does the honeybee get from the flower?
3-3: Honey.
Interviewer: Anything else?
3-3: Pollen.
Interviewer: So where is the pollen in the flower?
3-3: In the middle.

In grade 3 only 1 student stated that flowers and pollinators could not live without each other. What would happen if all the flowers or pollinators died would indicate that the population of the other would be effected.

Interviewer: Can flowers and insects live without each other?
3-1: No.
Interviewer: What would happen if all the flowers died?
3-1: No honeybees.
Interviewer: What would happen if all the honeybees died?
3-1: Wouldn't be any flowers.

Student 3-6 speculated that if all the flowers died, then pollinators would have to eat bugs.

Interviewer: Can flowers and insects continue to live without each other?
3-6: I don't know.
Interviewer: What would happen if all the flowers died?
3-6: Then the bees, butterflies, and other bugs that eat honey couldn't get nothing to eat.
Interviewer: Oh, they couldn't.
3-6: They would probably have to eat little bugs.

Grade 7 – Pollination Response Analysis

Table 9 summarizes grade 7 responses. Students in grade 7 definitely show advancement in understanding when compared with grade 3. All but two students show evidence of developing or developed understanding of pollination.

Table 9

Summary of Grade 7 Student Responses on Pollination

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
7-1	•Flowers attract pollinators •Honeybees attracted by pollen, honey, nectar •Pollinators and flowers cannot live without each other	•Honeybee takes pollen to other flowers •Bumblebee/butterfly get pollen, nectar •Yellow dust is pollen	□Developed Honeybee takes pollen to other flowers •Honeybees attracted by pollen, honey, nectar
7-2	•Flowers attract pollinators •Flowers and honeybees cannot live without each other	•Honeybee makes honey out of pollen •Flowers give butterflies food •Hummingbird eats pollen	□None evidenced
7-3	•Flowers attract pollinators •Honey attracts honeybee •Flowers and pollinators cannot live without each other	•Flowers give bumblebees hummingbirds, and butterflies food •Yellow dust is pollen	□None evidence
7-4	•Flowers attract pollinators •Honeybee gets honey from flower •Pollinators and flowers cannot live without each other	•Pollinators get food from flowers •Yellow dust is pollen •Pollen would not get transferred if all honeybees died	□Developing Honeybees transfer pollen
7-5	•Flowers attract pollinators •Pollinators take pollen from flowers •Pollinators and flowers cannot live without each other	•Flower gives bumblebee honey, nectar, and pollen •Nectar is a sweet liquid •Yellow dust in middle of flower is pollen	□Developing Pollinators obtain pollen from flowers
7-6	•Flowers attract pollinators •Nectar, color, pollen and smell attract pollinators •Pollinators and flowers cannot live without each other	•Pollinators sometimes get pollen from flowers •Butterflies transport pollen to other flowers •Yellow dust is pollen	□Developed •Nectar and fragrance attract pollinators Butterflies transport pollen

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
= Scientific concepts revealed during interviewing/mediation

Student 7-4 shows a developing understanding of pollination as evidenced by the use of the term "transferred" when referring to pollen.

Interviewer: Can flowers and insects continue to live without each other?
7-4: No.
Interviewer: What would happen if all the honeybees died?
7-4: Pollen would not get transferred to other places.
Interviewer: What would happen if all the flowers died?
7-4: All the honeybees would die.

Student 7-6 revealed that butterflies get nectar and sometimes pollen from flowers and that pollen lands in other flowers. Furthermore, the student indicated that pollination has to do with reproduction. The student showed thinking at the scientific level.

> Interviewer: Where do you usually see butterflies?
> 7-6: By the flowers.
> Interviewer: And what are they doing by the flowers?
> 7-6: Drinking nectar.
> Interviewer: Anything else?
> 7-6: Sometimes they get pollen.
> Interviewer: When the butterflies get pollen and go from flower to flower, how does that help the plant?
> 7-6: It lands into other flowers.
> Interviewer: Do you know what pollination is?
> 7-6: When they reproduce.

Grade 10 – Response Analysis

Grade 10 students showed some advancement over grade 7 students on the concept of pollination. All students in grade 10 show at least a developing understanding of pollination. Table 10 summarizes grade 10 responses.

Table 10

Summary of Grade 10 Student Responses on Pollination

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
10-1	•Flowers attract pollinators •Pollinators get honey and pollen from flowers •Pollinators and flowers cannot live without each other	•Butterflies like colorful, fragrant, and big flowers •Nectar is in the middle of flowers •Pollen is powdery	□Developing Big, colorful, and fragrant flowers attract butterflies
10-2	•Flowers attract pollinators •Honeybee gets honey from flower •Pollinators and flowers cannot live without each other	•Food, smell and color of honey attract honeybee •Color, shape, and fragrance attract pollinators •Yellow dust is pollen or nectar	□Developing Color, shape, and fragrance attract pollinators
10-3	•Flowers attract pollinators •Pollen and honey attract honeybees •Pollinators get pollen and honey from flowers •Pollinators and flowers cannot live without each other	•Yellow dust is pollen •Pollen is in middle of flower •If honeybees died, other pollinators could take over	□Developing •If honeybees died, other pollinators could take over
10-4	•Flowers attract pollinators •Pollen, nectar and color attract honeybees •Pollinators and flowers cannot live without each other	•Honeybee spreads pollen from one flower to another •Pollinators get nectar and spread pollen from one flower to another on wings •Yellow dust inside flowers is pollen	□Developed •Pollination is spreading of pollen flower to flower •Pollen, nectar and color attract honeybees
10-5	•Flowers attract pollinators •Pollinators get food from flowers •Pollinators and flowers cannot live without each other	•Yellow color attracts the honeybee to the flower •Yellow dust is in the middle of flowers	□Developing •Color attracts honeybees to flowers
10-6	•Flowers attract pollinators •Honeybees get pollen from flowers •Pollinators and flowers need each other for survival	•Honeybees are attracted to flowers by pollen, food, scent, and color •Yellow dust is pollen •Pollinators get pollen and food from flowers	□Developing •Color, fragrance, and pollen attract honeybees

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
= Scientific concepts revealed during interviewing/mediation

Student 10-4 demonstrated developed scientific understanding. The student knew that color attracted flowers and that a honeybee spreads pollen from flower to flower, Furthermore, the student defined pollination.

Interviewer: Why do you think the honeybee is on the flowers?
10-4: So he can suck the nectar from the flowers.
Interviewer: What attracts the honeybee to the flowers?
10-4: The scent of the pollen.
Interviewer: Anything else? Do you think the color of the flower might attract them?
10-4: Yes, because I heard that bees like yellow.
Interviewer: Where did you hear that?
10-4: Just around when I was a little kid.
Interviewer: Did somebody tell you that or did you see it on television or what?
10-4: We used to think that when we were little. We stayed away from wearing colors
like yellow.
Interviewer: Does the honeybee help the flower?
10-4: Uhm, yes.
Interviewer: How does it help the flower?
10-4: Because it spreads pollen from one flower to another.
Interviewer: Do you know what pollination is?
10-4: It's spreading pollen from one flower to another.

College Students- Pollination Response Analysis

All college students, 6 out of 6, have had extensive everyday experiences with pollination. Table 11 indicates that all students have a developed scientific conceptual understanding of pollination.

Table 11

Summary of College Student Responses on Methods of Seed Dispersal

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
C-1	•Flowers attract pollinators •Honeybee attracted by fragrance, pollen, honey, and nectar •Pollinators and flowers cannot live without each other	•Hummingbird gets pollen and nectar from flower •Other pollinators attracted by fragrance, honey, and nectar •Yellow dust is pollen •Nectar is deep in flowers	Developed •Pollen helps the flower for purposes of pollination Honeybees attracted by fragrance and nectar
C-2	•Flowers attract pollinators •Honeybees attracted by color, nectar, fragrance and pollen •Pollinators and flowers cannot live without each other	•Pollen is important for reproduction •Pollinators pick up pollen on wings and transfer •Other pollinators transfer pollen if one dies out	Developed •Pollinators help flowers by transferring pollen to other flowers •Honeybees attracted by color, nectar, fragrance and pollen
C-3	•Flowers attract pollinators •Pollinators transfer pollen elsewhere •Pollinators and flowers cannot live without each other	•Nectar is in the center of flowers •Yellow dust is pollen •Honeybees attracted by pollen, fragrance, color, and nectar	Developed •Pollination is transferring pollen and then fertilization Honeybees attracted by fragrance, nectar, pollen
C-4	•Flowers attract pollinators •Honeybees are attracted by color, nectar, fragrance, and honey •Pollinators and flowers cannot live without each other	•Yellow dust is pollen •Pollen fertilizes the egg •Hummingbird spreads pollen to pollinate the flower •Pollen fertilizes the egg so it can make a seed	Developed •In pollination, pollen gets onto the stamen •Pollinators pollinate the flowers with pollen •Honeybees attracted by color, nectar, fragrance and pollen
C-5	•Flowers attract pollinators •Honeybees are attracted by food, nectar, fragrance •Pollinators and flowers cannot live without each other	Pollinators attracted to flowers by food, nectar, fragrance •Yellow dust is pollen •Pollinator collects pollen on body parts to take to another flower	Developed •Pollination is getting pollen on the animal and putting on female part of another plant •Honeybees attracted by nectar, fragrance
C-6	•Flowers attract pollinators •Honeybee gets nectar from flower and disperses pollen when flying away •Pollinators and flowers cannot live without each other	•Pollinators get pollen on their feathers/wings and transfer to other flowers •Yellow dust is pollen •Pollen is important for reproduction	Developed •Pollination is the transfer of pollen to the flower Honeybee is attracted by nectar

*For Scientific Concepts: = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
= Scientific concepts revealed during interviewing/mediation

Cross-Age Analysis

A summary of pollination responses by grades 3 through college demonstrates an increasing level of conceptual understanding as shown in Table 12.

Table 12

Summary of Pollination Conceptual Development

Grade	Everyday Conceptual Experiences*	Transition Mediation/ZPD**	Scientific Conceptual Development***
3	6	6	4/2/0
7	6	6	2/2/2
10	6	6	0/5/1
C	6	6	0/0/6

*Everyday Conceptual Understanding by Number: Number with Everyday Understanding
**Transition/Mediation/ZPD: Number Revealing Additional Responses with Mediation
***Scientific Conceptual Development by Number: None evidenced/Developing/Developed

None of the grade 3 students understood pollination at the scientific level. Two students in grade 7 and one student in grade 10, and all 6 college students showed a developed scientific understanding of pollination as revealed by interview responses. Developing an understanding of pollination appears earlier than developing understanding about seed dispersal with most students having a developing understanding of pollination by grade 7.

Food Chains

Food chains represent the third interdependency concept. Table 13 lists potential everyday and scientific concepts that could emerge from interview responses for food chains. Following this table are results for card sorts for all grade levels. Analysis of the card sort results in conjunction with interview responses on food chains by grade level follows.

Table 13

Everyday and Scientific Concepts for Food Chains

Everyday Concepts	Scientific concepts
•Some animals eat only plants (the producers).	•Animals that only eat plants are herbivores
•Some animals consume other animals.	•Animals that consume other animals are carnivores and are primary, secondary, or tertiary consumers; animals eat other animals if the population of one declines.
•A food chain consists of the animals that eat the plants and animals that eat other animals	•Food chains represent interdependency among organisms.
•Some food chairs have overlapping feeders	•Food chains may have an element of a food web.

Food Chain Card Sorts

Data for card sorts for the two food chains illustrated some interesting results. The first food chain was the same as the one used to interview students. Card sort two differed from card sort one in that there were two possible correct ways to arrange the cards in card sort two. The tables illustrating the food chain card sorts are interpreted as follows. The top row indicates the correct order for food chain 1 and the two possibilities for food chain 2 (A & B). If a student initially arranged the cards as shown at the top of the column then only the student’s number is recorded in that column. If the student did not initially arrange the cards as shown at the top of the column then the initial arrangement of the cards is also described. The symbol, ⦸, means that the student did not arrange the cards in the manner indicated at the top of the column.

Table 14

Food Chain Card Sorts for Grade 3

Grade	Food Chain 1 Wolf Fox Rabbit Grass	Food Chain 2A Hawk Birds Insects Cherries	Food Chain 2B Hawk Birds Insects Cherries
3-1	3-1	3-1	⃠
3-2	3-2 Switched wolf and fox around	3-2 Reverse in order of Cherries, Hawk, Birds, Insects, and then corrected order without prompting	⃠
3-3	3-3 First placed wolf on bottom in reverse order then quickly moved wolf to top without prompting	3-3	⃠
3-4	3-4	3-4 First had Hawk, Insects, Bird, Cherries, then reversed bird and insects	⃠
3-5	3-5	3-5	⃠
3-6	3-6 First placed wolf on bottom in reverse order then switched to grass on bottom	⃠	3-6 Insects Cherries Then Insects Birds

⃠Blank space indicates student did not arrange food chain card sort in the respective format.

Table 15

Food Chain Card Sorts for Grade 7

Grade	Food Chain 1 Wolf Fox Rabbit Grass	Food Chain 2A Hawk Birds Insects Cherries	Food Chain 2B Hawk Birds Insects Cherries
7-1	7-1	7-1 Reverse order with producer on top	⃠
7-2	7-2	⃠	7-2
7-3	7-3 First had grass on top and wolf on bottom then switched	⃠	7-3 First had 2A Arrangement then switched to 2B arrangement
7-4	7-4	⃠	7-4
7-5	7-5	7-5	7-5
7-6	7-6 Reversed Fox and Wolf Put Fox on top	7-6	⃠

⃠Blank space indicates student did not arrange food chain card sort in the respective format.

Table 16

Food Chain Card Sorts for Grade 10

Grade	Food Chain 1 Wolf Fox Rabbit Grass	Food Chain 2A Hawk Birds Insects Cherries	Food Chain 2B Hawk Birds Insects Cherries
10-1	10-1	10-1	⃠
10-2	10-2	10-2	⃠
10-3	10-3	10-3 First did this arrangement	10-3 Switched birds and Insects to side by side
10-4	10-4	10-4	⃠
10-5	10-5	10-5	⃠
10-6	10-6	10-6	⃠

⃠Blank space indicates student did not arrange food chain card sort in respective format.

Table 17

Food Chain Card Sorts for College Students

Grade	Food Chain 1 Wolf Fox Rabbit Grass	Food Chain 2A Hawk Birds Insects Cherries	Food Chain 2B Hawk Birds Insects Cherries
C-1	C-1	⃠	C-1
C-2	C-2	C-2	C-2
C-3	C-3	C-3	⃠
C-4	C-4	C-4	⃠
C-5	C-5	C-5	⃠
C-6	C-6	C-6	⃠

⃠Blank space indicates student did not arrange food chain card sort in the respective format.

Some students in grades 3 and 7 moved the cards around before settling on an arrangement. Tenth graders and college students did not rearrange the cards after the initial attempt except to illustrate both possibilities for food chain 2.Table 18 summarizes the card sort results across grade levels. All students successfully arranged food chain 1. Some students noted an element of a food web in food chain 2 and arranged the card sort accordingly (2B). Seventh graders were more likely to show both arrangements.

Table 18

Summary of Food Chain Card Sorts

Grade	Food Chain 1	Food Chain 2A*	Food Chain 2B*
3	6	6	1
7	6	4	5
10	6	6	1
College	6	5	2

*Some students in each grade arranged the food chains in both ways.

Grade 3- Food Chain Response Analysis

Conceptual development of food chains is similar to conceptual development for seed dispersal or pollination. None evidenced indicates that students had everyday experiences but no scientific understanding. Developing indicates that the student expressed at least one scientific concept using either the formal terminology or a synonym. Developed indicated conceptual understanding at the scientific level. For developed, students stated at least two scientific concepts. If a student said that animals eat animals, the response was considered developing. If a student qualified that animals eat other animals if the population of one declines, the response was considered scientific. Since the card sort data were grouped with interview data for food chains, sorting food chains by two methods was also considered scientific or formal understanding.

Table19 indicates the everyday experiences as well as mediated responses of students to the interview protocol. Data from the food chain analysis as well as interview responses were used to construct column 3, scientific conceptual development. Data from Table 19 above shows that student 3-1 had progressed to at least a developing scientific understanding in relation to rabbits being herbivores. Student 3-1 not only knew what rabbits eat, but also had an understanding of the cause and effect of food interrelationships or interdependencies. If all the plants died, then the rabbit would die, for rabbits, which are herbivores, are dependent on plants for survival. Student 3-1 demonstrated an understanding of interdependency of rabbits and plants by the following responses:

> Interviewer: What does the rabbit eat?
> 3-1: Grass
> Interviewer: Suppose no grass, what would the rabbit eat?
> 3-1: A carrot.
> Interviewer: Suppose all the plants died. What would happen to the rabbit?
> 3-1: Would die.

Data table 19 is shown below.

Table 19

Grade 3 Responses to Food Chain Protocol

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
3-1	•Rabbits eat grass and carrots •Rabbit would die if all plants died	•Wolf would eat meat/ a fox •Mouse would eat cheese but not grass or seeds	□Developing Rabbits eat plants Rabbits would die without plants
3-2	•Rabbit will eat green stuff-- leaves, grass; if no grass or leaves, would eat blueberries, carrots •Would drink something if all plants died •Wolf eats other animals •Fox eats other animals	•If wolf ate all the rabbits, fox would eat something else eaten by wolves	□Developed Rabbits eat plants Animals can eat other animals if the population of one declines
3-3	•Rabbit eats green leaf/ grass/pollen •Rabbit will eat blueberries if no grass is growing •Rabbit would have no food if all the plants died •Fox eats plants •Wolf would eat a fox	•Rabbit would die w/o food •Wolf eats animals •Fox eats animals •Fox might eat a rabbit •If the wolf ate all the rabbits, fox would eat a wolf •Birds eat seed and flowers	□Developed Rabbits eat plants Rabbits would die without plants Animals eat other animals if the population of one declines
3-4	•Rabbit eats plants, grass, carrots •Rabbit would still eat carrots if all the plants died •Wolf eats meat, fox •Bird eats bird food	•Rabbit probably die if every plant including carrots died •Wolf would also eat rabbit •Frog eats flies •Hawk eats little seeds	□Developing Rabbits eat plants Animals eat other animals
3-5	•Rabbit will eat lettuce, grass, carrots, rabbit food, milk •Fox will eat animals •Wolf will eat buffalo, turkey, lion •Frog eats insects like butterflies	•Fox will eat small animals like rabbits, ducks, chickens •If wolf eats all the rabbits, the fox would chase the wolf	□Developing Rabbits eat plants Animals eat other animals
3-6	•Rabbit will eat small food like carrots, grass, etc. •Fox eats meat •Wolf eats meat •Lizards eat flies; they are sticky	•If all the plants died, the rabbit would die •Fox would eat the rabbit	□Developed Rabbits eat small food/plants Animals eat other animals ▪ Both insects & birds eat cherries

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
▪ = Food chain card sort when food web concept used
= Scientific concepts revealed during interviewing/mediation

Student 3-4 stated that a rabbit would still eat carrots if all the plants including grass died. With mediation, student 3-4 then responded that the rabbit would probably die from hunger if every plant including carrots died, a cause and effect concept. The student clearly demonstrated an understanding of food chains and the interdependency between producers and consumers and between the different levels of consumers as shown by the following:

> Interviewer: What do you see in this picture?
> 3-4: A bunny rabbit.
> Interviewer: And what do you think the rabbit is going to eat?
> 3-4: The plants (in the picture—grass, leaves).
> Interviewer: And what else? What plant is this?
> 3-4: Grass.
> Interviewer: What might it eat other than the plants here? What are some other things rabbits eat?
> 3-4: Carrots.
> Interviewer: All right, carrots. Suppose no grass is growing or none of these plants are growing. Suppose all the plants died. What would the rabbit do?
> 3-4: Still eat carrots.
> Interviewer: Suppose all the carrots died too. Carrots are plants. Suppose every plant died. What would the rabbit do?
> 3-4: It would probably die too from hunger.

When asked what animals the wolf would eat, student 3-4 responded as follows:

> Interviewer: What does the wolf eat?
> 3-4: Meat.
> Interviewer: What animal would the wolf eat?
> 3-4: The fox.
> Interviewer: Do you think it might also eat the rabbit?
> 3-4: Yes. I think it would eat both of them.
> Interviewer: Suppose the wolf ate up all the rabbits. What would the fox do?
> 3-4: It would run away, because it is probably scared of the fox, I mean the wolf.

Note that student 3-4 indicated that a wolf would eat both foxes and rabbits, demonstrating that animals eat other animals in a food chain or food web that is that animals are interdependent for their own survival.

All grade 3 students indicate that rabbits consume a variety of plant type food. Plant food tends to be small, as are rabbits. Upon analyzing the first question asked about what would happen if all the plants died, one student in grade 3 immediately gave a cause and effect answer that the rabbits would die if all the plants died. With additional questions by the interviewer, that is, with mediation within the zone of proximal development, 2 additional students in grade 3 responded similarly with the cause and effect reasoning that the rabbits would die if all the plants died. Over all, mediation was rarely needed to generate responses to the food chain protocol. Food chains are a part of formal instruction at a young age, even in kindergarten.

Upon additional interviewing, all students in grade 3 responded that some animals eat other types of animals, an everyday concept that students would have observed over time, and also a scientific concept. Most students have been taught or had in their reading books that animals consume other animals. The fact that grazing animals consume plants or producers and certain other animals such as foxes and wolves consume other animals is a part of their scientific or formal learning. Whether the students link feeding relationships to the concept of a food chain terminology wise was not a part of the interview protocol for this study.

Grade 7- Food Chain Response Analysis

Food chain responses from grade 7 students did not differ from those of grade 3. Half of the students indicated developing understanding, half indicated developed understanding. Table 20 summarizes grade 7 responses to the food chain protocol.

Table 20

Summary of Food Chain Responses by Grade 7

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
7-1	•Rabbit will eat grass, flowers, carrot •Rabbit dies if all the plants died •Fox or wolf will eat rabbits •Mice eat grass; frogs eat insects; butterflies eat pollen; squirrels eat nuts	•Fox would eat other animals if the wolf ate all the rabbits	Developed Rabbits eat plants Animals eat other animals if the population of one declines
7-2	•Rabbit will eat grass, plants, carrots •Fox will eat a rabbit •Wolf would eat a rabbit •Frogs eat insects	•Fox would eat an animal if a wolf ate all the rabbits	Developed Rabbits eat plants Animals eat other animals if one population declines
7-3	•Rabbits eat carrots, leaves, grass •Rabbits would die if all the plants/grass died •Fox will eat rabbits •Wolf will eat rabbits •Dog would eat a cat; cat would eat a rat; frog would eat ants, flies	•Fox would search for something else if the wolf ate all the rabbits.	Developed Rabbits eat plants Animals eat other animals if the population of one declines
7-4	•Rabbit eats grass/carrots/plant/flower •Rabbit dies if all the plants died •Fox will eat a rabbit •Wolf would eat the fox •Fox dies if wolf eats all rabbits •Frogs eat insects	•Fox might eat rabbits	Developing Rabbits eat plants Animals eat other animals
7-5	•Rabbit will eat leaf, grass, carrots; would eat carrots if all the plants died •Wolf would probably eat something smaller than itself •Fox would probably eat rabbits •Frogs eat insects; snakes eat rats; bigger fish eat smaller fish	•Fox would have to look for more food and grass if the wolf ate all the rabbits	Developing Rabbits eat plants Animals eat other animals
7-6	•Rabbit eat grass/leaves/maybe bugs •Rabbits eat bugs if all the plants died •Wolf would eat bigger animals •Fox wouldn't have anything to eat if the wolf ate all the rabbits	•Fox would eat squirrels or other rabbits if the wolf ate all the rabbits	Developing Rabbits eat plants Animals eat other animals

*For Scientific Concepts: = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
▪ = Food chain card sort when food web concept used
= Scientific concepts revealed during interviewing/mediation

Student 7-3 stated that the rabbit would die if all the plants died. Furthermore, if all the rabbits died, the fox would have to search for another animal. Students 7-3 responded as follows to the food chain protocol.

Interviewer: What do you think the rabbit will eat?
7-3: I think it will eat carrots?
Interviewer: Carrots and what else? What is in the picture that it might eat?
7-3: Leaves and grass.
Interviewer: And suppose no grass is growing. What else could the rabbit eat?
7-3: Uhm. It would die.
Interviewer: It could go out and get some other plants or something. Suppose all the plants died. What would the rabbit do?
7-3: Die.
Interviewer: What do you think the fox is going to eat?
7-3: The rabbit.
Interviewer: What is the wolf going to eat?
7-3: The rabbit.
Interviewer: Suppose the wolf ate all the rabbits. What would the fox do?
7-3: Go out and search for something else.

The student understood cause and effect, that if a food source is eliminated, either the animal will die or search for another food source.

Grade 10 - Food Chain Response Analysis

For grade 10 students' responses to the food chain protocol, 3 showed developing understanding and 3 showed developed scientific understanding. A developed understanding indicated that students stated that an animal would eat another animal if the population of one animal declined. If the student stated that an animal died if the population of one consumer declined, then the student demonstrated a developing scientific understanding. Table 21 below summarizes grade 10 responses to the food chain protocol.

Table 21

Food Chain Responses for Grade 10

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
10-1	•Rabbits eat lettuce/carrots/grass •Rabbits would probably eat nothing if the plants died •Rabbit probably die if all plants died •Fox would eat rabbits /hawk •Mice eat leaves; bears eat fish	•Fox would eat rabbits, squirrels and birds if the wolf ate all the rabbits	□Developed Rabbits eat plants Animals eat other animals if the population of one declines
10-2	•Rabbit will eat grass, bugs, or something on the ground, other plants, and leaves •Fox would probably die if the wolf ate all the rabbits •Snakes eat rats	•Fox will eat leaves, grass, bird, and prey •Wolf would eat a fox	□Developing Rabbits eat plants Animals eat other animals
10-3	•Rabbit eat grass/berries/carrots •Rabbit would die if all the plants died •Fox will eat rabbits •Wolf will eat the fox •Frogs eat flies	•Fox would die if wolf ate all the rabbits	□Developing Rabbits eat plants Animals eat other animals
10-4	•Rabbit will eat grass, insects, maybe vegetables or apples •Rabbit would eat nothing if all the grass died •Fox will eat rabbits or small rodents •Wolf will eat almost anything around	•Rabbit will eat grass and leaves •Wolf may eat the fox •Fox will eat chickens if all the rabbits die	□Developed Rabbits eat plants Animals eat other animals if the population of one declines
10-5	•Rabbit eats carrots/vegetables •Rabbit will die or find another plant to eat if all the grass dies •Wolf will eat deer and stuff	•Fox would find something else if the wolf ate all the rabbits	□Developed Rabbits eat plants Animals eat other animals if the population of one declines
10-6	•Rabbits will eat grass	•Rabbits will eat seeds from roots and stuff •Foxes would probably eat rabbits	□Developing Rabbits eat plants Animals eat other animals

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
▪ = Food chain card sort when food web concept used
= Scientific concepts revealed during interviewing/mediation

An analysis of some grade 10 students' responses to food chains indicates increasing conceptual understanding. Student 10-4 responded as follows:

Interviewer: What would happen if all the grass died? What would the rabbit eat?
10-4: Nothing.

Interviewer: What will a fox eat?
10-4: Rabbits or some small rodents.
Interviewer: What does a wolf eat?
10-4: Almost anything you put in front of it.
Interviewer: Will the wolf eat the fox?
10-4: Maybe.
Interviewer: Suppose all the rabbits died. What would the fox eat?
10-4: It will eat chickens and other things like that.

Note that student 10-4 showed a developed understanding because the fox would eat another animal if all the rabbits died. Since a rabbit is a first order consumer and eats only plants, then the rabbit might die. Other students stated that the rabbit would eat other plants. A fox is a second order consumer and may find other animals to eat.

College Students- Food Chain Response Analysis

Table 22 summarizes food chain interview response data for college students. All college students demonstrated scientific conceptual understanding of food chains. Each student stated at least 3 different scientific concepts pertaining to food chains. Student C-3 had a thorough understanding of food chains and webs. Student C-3 responded as follows:

Interviewer: What would the fox eat?
C-3: The fox would eat the rabbit.
Interviewer: What would the wolf eat?
C-3: The fox and the rabbit.
Interviewer: Can you think of anything else the wolf would eat?
C-3: They usually go for the smaller things like moles. I know wolves control the fox population. Wolves can eat deer and bigger things.

Table 22.

College Students Responses to Food Chains

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development*
C-1	•Rabbit will eat grass/plants/leaves •Wolf probably eats the fox, grass, and meat, •Fox will eat rabbits; will eat grass & mice if wolf ate all rabbits •Frog eats insects; hawk will eat smaller birds, snakes	•Rabbit would probably not live without plants	□Developed Rabbits eat plants Animals eat other animals if the population of one declines.
C-2	•Rabbit will eat green vegetation, grass •Rabbits die if all the plants died •Fox eats smaller animals, such as rabbits, rodents	•Fox would eat another small animal if the wolf ate all the rabbits	□Developed Rabbits eat plants Animals eat other animals if the population of one declines.
C-3	•Rabbit will eat dandelion leaves, bushes; dies if all the plants died •Fox eats rabbits, moles •Wolf eats fox and rabbit •Frogs eat flies; mice eat wheat or seeds; rats eat meat	•Rabbits will eat grass •Wolves control the fox population; can eat deer and bigger things	□Developed Rabbits eat plants Animals eat other animals •Animals can eat different orders of consumers; wolves eat rabbits, foxes
C-4	•Rabbit will eat vegetation, fruit, berries, plants; probably would starve if all plants died •Fox eats meat-squirrels, animals •Wolf eats bigger animals •Fox would have to eat other foods if wolf ate all the rabbits	•None	□Developed Rabbits eat plants Animals eat other animals if the population of one declines
C-5	•Rabbits eat grass, leaves, and little things; could die if all plants died •Fox would eat the rabbit; eats other animals if wolf ate all rabbits •Wolf could eat the fox or rabbit	•Foxes will eat any small animal like rats	□Developed Rabbits eat plants Animals eat other animals if the population of one declines
C-6	•Rabbit eats grass, all greenery •Rabbit dies if all the plants died •Fox eats rabbits, small rodents •Wolf eats any meat-foxes •Fox dies if wolf ate all rabbits •Animals eat different animals	•Rabbit will eat dandelion leaf	□Developed Rabbits eat plants Animals eat other animals Foxes and wolves eat different animals

*For Scientific Concepts: □ = Development: None evidenced, Developing, Developed
• = Concepts stated during interviewing
▪ = Food chain card sort when food web concept used
= Scientific concepts revealed during interviewing/mediation

Cross-age Summary

The food chain concept contains mainly elements of understanding at the everyday level. Scientific understanding requires comprehending the fact that animals find another food source if the population of one plant or animal declines. Students across grade levels showed increasing understanding of food chains from grade 3 to college.

Table 23 summarizes the food chain protocol and card sort data. All students revealed further knowledge through mediation. Pictures assisted in guiding students' responses to food chain questions. Scientific conceptual understanding progressed from 2 students for grade 3, to 3 students each for grades 7 and 10, and to all college students. The food chain concept is understood at an earlier age than are seed dispersal and pollination.

Table 23

Food Chain Summary

Grade	Everyday Conceptual Experiences	Transition Mediation/ZPD	Scientific Conceptual Development
3	6	6	0/4/2
7	6	6	0/3/3
10	6	6	0/3/3
C	6	6	0/0/6

*Everyday Conceptual Understanding by Number: Number with Everyday Understanding
**Transition/Mediation/ZPD: Number Revealing Additional Responses with Mediation
***Scientific Conceptual Development by Number: None evidenced/Developing/Developed

Summary

Students across grade levels demonstrated varying understanding of everyday concepts and scientific concepts. Seed dispersal and food chains showed somewhat similar understanding across grade levels. Food chain data indicated that the concept involves more everyday experiences. Most students were more familiar with food chains than with seed dispersal and pollination, concepts that involve development and perhaps formal instruction.

Table 24 indicates the most often used concepts by students during interviews on seed dispersal. The second column states students mediated responses. The third column shows scientific concepts of seed dispersal that students understand once reaching true conceptual development.

Table 24

Everyday Concepts, Mediated Concepts, and Scientific Concepts on Seed Dispersal

Everyday Concepts (Experiences)	Transition Mediation/ZPD	Scientific Concepts
• Plants grow from seeds	•Seeds carried by different agents	•Seeds are dispersed by different methods (people, animals, wind, and water) to different places to grow.
•Seeds stick to humans and animals	• Seeds that stick to humans and animals/birds drop off and grow	•Seeds have adaptations for dispersal (sticky, barbs, prickles, wings, feathery).
•Wind (Seeds in air)	•Wind carries seeds to other places	• Seeds are interdependent with their dispersing agents.
•Water (Seeds in stream)	•Seeds carried to other places by water can grow	•Seed dispersal is the scattering, spreading, or transporting of seeds

Table 25 indicates the most often used concepts by students during interviews on pollination. The second column states students mediated responses. The third column shows scientific concepts of pollination that students understand once reaching true conceptual development.

Table 25

Table of Everyday and Scientific Concepts on Pollination including Mediation

Everyday Concepts (Experiences)	Transition Mediation/ZPD	Scientific Concepts
•Flowers attract honeybees, hummingbirds, bumblebees, butterflies, and other insects.	•Butterflies are attracted by food, color, and fragrance •Yellow color attracts the honeybee	•Honeybees, hummingbirds, bumblebees, butterflies, and insects are pollinators attracted by color, nectar, and fragrance
•Flowers provide food (Honey)*for honeybees, hummingbirds, bumblebees, and butterflies.	•Honeybees get honey, nectar, and pollen from flowers	•Food provided by flowers for pollinators includes nectar and pollen.
•Pollinator gets pollen on body parts; takes to other flowers	•Yellow dust is pollen •Pollen in middle of flower •Pollinators pick up pollen; transport the pollen from flower to flower.	•Pollination is the transfer of pollen from one flower to another.
•Flowers can't live without honeybees •Honeybees can't live without flowers	• Flowers and pollinators cannot live without each other	•Flowers and pollinators are interdependent.

*Honey is a synonym for nectar.

Table 26 consists of food chain responses most often used in interviews.

Table 26

Food Chain Interview Responses

Everyday Concepts (Experiences)	Transition Mediation/ZPD	Scientific Concepts
•Rabbit will eat green vegetation, grass •Rabbit would die if all the plants died	Rabbit will eat a dandelion	Rabbits eat plants only
•Fox eats smaller animals, such as rabbits	•Foxes will eat any small animal such as rats, moles	Animals eat other animals sometimes, depending on the size
•Wolf would eat the fox and the rabbit	Wolf eats rabbit and fox	Foxes and wolves eat different animals
Animals eat more than one kind of animal	Some animals may die if another animal not available	Animals eat other animals if the population of one declines

Summary of Results

Three research questions identified the purposes of this study. To summarize findings each research question will be considered in this section.

Research Question 1: What everyday and scientific concepts do students have pertaining to biological interdependency of pollination, food chains, and seed dispersal?

This research question was thoroughly addressed in the previous sections, so only a recap will be provided here. Most students reported everyday experiences with all three concepts. Elements of conceptual understanding were revealed to be within the experiences of students depending on concept and grade level.

Research Question 2: What patterns of student knowledge of interdependency in pollination, food chains, and seed dispersal are evident across grade levels?

Again, this question was addressed in above sections and is summarized as follows. College students have fully developed scientific concepts related to seed dispersal. Third graders do not. Seventh and tenth grade students' understanding varies by individual. Conceptual understanding of pollination is not evidenced by third graders, varies with grades 7 and 10, and is generally developed by college students. Understanding of food chains is indicated as early as grade 3, and may be fully developed by grade 7.

Research Question 3: How can results from the interviews be used to construct an understanding of a student's zone of proximal development (ZPD) with respect to the interdependency concepts of pollination, food chains, and seed dispersal?

The zone of proximal development (ZPD) is defined as follows: the difference between what a student can do alone today and what a student can do with assistance tomorrow. Some students understand a concept at or below grade level, whereas other students understand a concept two or three grade levels ahead of their chronological age. Students may understand one concept at grade level, yet understand another concept above grade level. The ZPD is dynamic, and students can have more than one ZPD. Therefore having a general understanding of students' zone of proximal development across grade level for major concepts is important in planning instruction. The results from this study assist with understanding students' zones of proximal development (ZPD) across grade levels on the concepts of seed dispersal, pollination, and food chains. Students' zones of proximal development showed variation by grade level.

Seed dispersal

An analysis of grade 3 results for seed dispersal provides some information about zones of proximal development. Generally, grade 3 students showed everyday experiences with seed dispersal, yet did not understand that seeds are dispersed by dispersing agents with potential reproductive advantage of growing in different locations. Mediation revealed one grade 3 students who showed a beginning understanding of seed dispersal. However, for most of the 3rd grade students, understanding of the science concept of seed dispersal was outside of their ZPD.

Grade 7 results showed variation in the students' zones of proximal development. Students had observed that plants grow from seeds and that seeds attach to people and animals, yet understanding the experiences as belonging to the concept of seed dispersal was not evident to three out of the six students. Following mediation, two grade 7 students indicated that seeds stick to people and animals to travel to other locations to grow, indicating a developing understanding of the concept of seed dispersal. Following mediation, one grade 7 student further observed that seeds stick to people and animals and so are agents to move the seeds around to other places to grow, indicating further development. For some grade seven students, seed dispersal as a scientific concept was within their ZPD. For others there was no indication that understanding could be mediated at this time.

Grade 10 students showed a similar pattern of understanding within the zone of proximal development. Again, three grade 10 students demonstrated no evidence of understanding seed dispersal. The students noted that plants grow from seeds, and that seeds stick to people and animals, yet did not understand that seeds stick for the purpose of dispersal. Two grade 10 students exhibited a developing understanding, indicating that seeds stick then fall in different places as people and animals move around suggesting that seed dispersal was within the zone of proximal development for the two students. One grade 10 student used the term “spread,” a synonym for seed dispersal, and stated that seeds falling in different places is spreading of seeds, and that pollination results in seed growth, clearly indicating a developed understanding of seed dispersal.

Results on seed dispersal for college students demonstrated advancement in understanding the scientific concept of seed dispersal. All college students used the term “dispersal” or used a synonym for dispersal. Furthermore, college students indicated that seeds are sticky to aid in transport, an understanding that seeds have adaptations to assist with dispersal. In addition, the college students stated the four methods of seed dispersal, further indicating well-developed understanding of seed dispersal.

In summary, interview results demonstrated students’ zones of proximal development across grade levels. Seed dispersal as a scientific concept is not within the zone of proximal development for most grade 3 students. Students in grades 7 and 10 are beginning to understand seed dispersal, meaning that the concept may be within their range of understanding, but will vary from individual to individual. College students show complete development, more everyday experiences, and enhanced formal understanding. For these students, tying the notion of seed dispersal to interdependency is either accomplished or well within their ZPD.

Pollination

Constructing an understanding of students' zones of proximal development on pollination showed similar patterns when compared to seed dispersal. Again, students' concepts vary across grade levels. The formal concept of pollination falls somewhat more into the younger students' zones of proximal development than did seed dispersal. For grade 3 students, two students showed a developing scientific concept on pollination. For example, one student stated that pollination has to do with pollen. Another student stated that pollinators obtain nectar and pollen from flowers. An indication of understanding pollen shows that the student is beginning to understand the concept of pollination, that pollination is probably within these students' zones of proximal development.

For grade 7 students, understanding the concept of pollination has developed further. Only two students showed no evidence of understanding pollination. Two grade 7 students demonstrated a developing understanding of pollination, indicating an understanding of the importance of pollen, and that pollen is transferred by pollinators. Two grade 7 students showed a developed understanding. The students observed that not only did pollinators transport pollen, and that the pollinators carried the pollen from one flower to another, but also that pollen and nectar attract the pollinators.

Among grade 10 students, 5 showed developing understanding and one demonstrated developed understanding. Most tenth grade students showed increased everyday experiences, developed in chronological age, and may have had further formal instruction, factors that indicate an elevated zone of proximal development for pollination. The student with developed understanding used the term "pollination," an indication of formal instruction.

All college students showed a developed level of understanding related to pollination. The students used scientific terminology as indicated by the term, pollination, and stated concepts identified in the table of scientific concepts at the beginning of the pollination results. Clearly, the ZPD made a dramatic shift from grade 3 to college. College students probably related to further formal instruction, and show a well developed understanding of the concept. In addition, some college students study independently, a means of increasing their understanding of the natural world.

<u>Food Chains</u>

Understanding interview results can be used to construct an understanding of students' zones of proximal development with respect to food chains. Card sort data was included with food chain interview data to determine conceptual understanding of the food chain concept. Results indicated that the food chain concept is understood at an earlier age than are the concepts of seed dispersal and pollination. Developing indicated that the students observed that rabbits eat plants and that animals consume other animals. Developed showed that in addition, the students also recognized that as populations declined, an animal would consume a different animal, usually smaller. Furthermore, the students arranged card sort. Card sort 1 was more linear, whereas card sort 2 had a food web element, indicating an overlapping feeding arrangement of the first order consumers. Everyday experiences, development, chronological age, mental age, and formal instruction assisted in evaluating food chain understanding. Students demonstrated increased understanding of food chains across grade levels. Food chain results for grades 3, 7, and 10 were the same: 3 students showed developing understanding and 3 showed developed understanding. The food chain concept was within the zone of proximal development even among grade 3 students.

In summary, results from the interviews and card sorts for food chains can be used to construct an understanding of students' zones of proximal development. The dynamic nature of the ZPD indicates that students across grade levels vary in conceptual understanding, development, everyday experiences, formal instruction, and interest in learning. Students can have more than one ZPD. The ZPD shifts from one grade level to another and from chronological age to mental age. Students who understand the concepts of seed dispersal, pollination, and food chains may have embraced the concepts of interdependency or have the potential (ZPD) to fully develop this overarching concept.

Summary of Scientific Concepts for Seed Dispersal, Pollination, and Food Chains

Table 27 shows a summary of scientific conceptual understanding across grade levels for all three interdependencies—seed dispersal, pollination, and food chains.

Table 27

Comparison Table Across Grade Levels: Seed Dispersal, Pollination, and Food Chains

Grade	Seed Dispersal	Pollination	Food Chains
3	5/1/0	4/2/0	0/4/2
7	3/2/1	2/2/2	0/3/3
10	3/2/1	0/5/1	0/3/3
College	0/0/6	0/0/6	0/0/6

*Everyday Conceptual Understanding by Number: Number with Everyday Understanding
**Transition/Mediation/ZPD: Number Revealing Additional Responses with Mediation
***Scientific Conceptual Development by Number: None evidenced/Developing/Developed

Graphic representations for Table 27 are located in Appendix D. The data indicated the increasing conceptual understanding across grade levels from seed dispersal to pollination, then to food chains. Food chains and pollination are more within the students' zones of proximal development than is seed dispersal. The data illustrated the continuum of the dynamic zones of proximal development across grade levels.

Chapter 5

Discussion and Significance of the Study

Vygotsky believed that children could learn concepts at any age provided parents, teachers, or competent peers assisted with their understanding, and the instruction was located within the students' zones of proximal development (ZPD). Of course, children vary in potential. Children first learn everyday concepts, then scientific concepts. Vygotsky concluded that concepts that evolved to fruition during adolescence were already present in the young child.

Analysis and synthesis of the results of this cross-age study focused on two major themes. First, students' everyday concepts of natural phenomena, specifically interdependency, are viewed as a coherent framework of their 'commonsense interpretation of their experiences in living in the world' (Driver, 1978). Especially at an early age, children's experiences represent a conglomerate of ideas from various sources, including, first and foremost, their own observations and interpretation of the natural world, and ideas from their family, peers, teachers, and activity groups. In thinking about students' responses to questioning, keep in mind that children may be, and often are given information that can be incorrect or misleading. Younger students believe what is explained, whereas older students begin to think about and question what they are taught. Students' early knowledge is not viewed as misunderstanding, but understanding based on their constructive interpretation of prior experiences. Students' ideas represent alternative frameworks or interpretative models and are not necessarily a product of Piagetian stage theory of development (Driver, 1978).

Naturally, children progress in their experiences and instruction from grade 3 to grade 7 to grade 10 to college level. Children's learning is not limited to developmental stage, but dependent on existing ideas about a phenomenon, such as interdependency, for example. Driver and Easley (1978) proposed that cognitive development might be more like a series of

Kuhnian paradigm shifts with new ideas pertaining to a phemomenon replacing, interweaving, or correcting previous understanding. Driver's theory coincides with Vygotsky's theory of constructivism. Vygotsky believed that children could learn beyond their developmental stage with proper mediation within their zone of proximal development (ZPD). Children actually have a continuum of zones of proximal development, corresponding to a series of Kuhnian paradigm shifts, meaning that children constantly revise and upgrade their knowledge and understanding of phenomena of the world, including the interdependency concepts (See Figure 1).

Vygotsky's Zone of Proximal Development (ZPD)

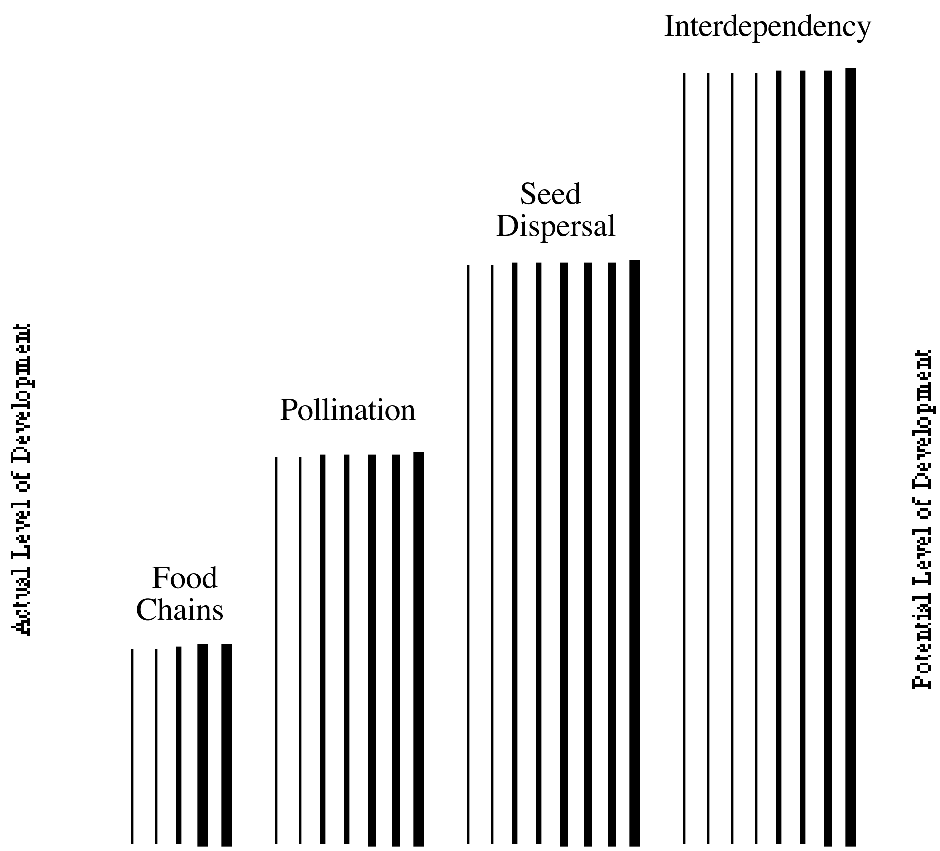

Figure 1. Vygotsky's zone of proximal development (ZPD) is a continuum of degrees of understanding concepts. Students have a zone of proximal development for each interdependency. The results of this study show the hierarchy of understanding the interdependency concepts in this study, including interdependency as all encompassing.

Prior experience and preinstructional knowledge result in unstable frameworks that students eventually use to reconstruct their understanding following formal instruction. Driver, et. al. (1994) discussed a constructivist view of learning based on the research of Vygotsky and his students. The role of a teacher is to introduce scientific concepts and to guide students toward making sense of their prior or everyday experiences. Formal instruction often includes more knowledge at the everyday or concrete level than at the formal or scientific level. Students use everyday knowledge to construct understanding leading to scientific or formal concepts. Following instruction, students have to re-construct their knowledge to incorporate new information. By interweaving prior experience with formal concepts, students reach a level of scientific or formal conceptual understanding. West and Pines (1985) indicated that formal and informal concepts must be integrated to form a complete concept and that the concepts intertwine like a vine. Everyday concepts are concrete and contextual; scientific concepts are abstract and non-contextual. A cross-age study provides an excellent method to track the development of children's conceptual progression across grade levels

Children develop true concepts during adolescence, yet the knowledge base was present at a much younger age and ready to develop in much the same way as an embryo develops. Most notably, Vygotsky believed that children of the same age could have a different level of conceptual understanding and therefore different zones of proximal development. For example, in this study for the concept of seed dispersal, grade 7 students showed variation in understanding, either no evidence, developing, or developed understanding, thus indicating differences in the ZPD.

According to research by Vygotsky, a study observing, comparing, and evaluating the genetic process of concept formation in 300 children, adolescents, and adults explained fundamental laws that govern the development of the process (van der Veer & Valsiner, 1994).

> The basic conclusion of our investigation in the genetic context can be formulated as a general rule, which says that the roots of development of the processes which afterwards lead to concept formation, reach back to early childhood, but they reach maturity only in adolescence, and those intellectual

> functions which form and develop are the ones which, in their particular combinations, make up the psychological basis of the process of concept formation. It is only when the child turns into an adolescent that the final transition into the realm of thinking in concepts can occur. Not a single form of intellectual activity, not even the ability to draw conclusions, makes its appearance for the first time in adolescence. In reality, the central thinking process, including the ability to draw conclusions, is already to be found in children. Both in the realm of the systems which process perceptions (selection, set, categorical perception, and processing classification) and in the sphere of logical connections (concept, judgment, inference, criticism), no completely new forms of psychological functions and actions appear in children of school age. All these are in existence earlier, but during school age they undergo considerable development, which can be seen in their being used in a more differentiated, subtle and frequently even more conscious fashion. (p. 189)

Concept development includes abstraction, analysis, and synthesis in formation, as well as a role of perception. Phases in the development of concepts according to Vygotsky include the development of pseudoconcepts, the development of complexes, the formation of unordered heaps, and ultimately the formation of true concepts. The roots of the development of true concepts have their origin in early childhood. True concepts transition by the time of adolescence.

In the cross-age study of seed dispersal, pollination, and food chains, similarities in the development of concepts were observed across grade levels. For example, younger children tended to use the concept of honey to coincide with the concept of nectar. In older children or in adolescents, nectar was more likely to be used than was honey. In this context, children have an understanding of the more familiar, concrete concept of honey, for honey is a food to many. Through the development of scientific concepts in a formal environment, the concept of nectar gradually evolves, for nectar, especially the role of nectar, is a more abstract term, a scientific concept. One does not see nectar when observing flowers, but the concept of nectar is mediated through schooling through the construction of concepts leading from honey to pollen to nectar.

According to Vygotsky (Rieber & Carton, 1987, p. 130),

> The unique intellectual formations present in the preadolescent period are, in fact, functionally equivalent to the true concepts that mature later. However, experimental analysis indicates that their psychological nature, their constituents, their structure, and their mode of activity differ significantly from those of the true concept. These formations have much the same relationship to the true concept that the embryo has to the mature organism. Similarly, just as the elements of the adolescent's future sexuality and sexual attraction are present in infancy, the elements and constituents of the adolescent intellect are present in the young child. The formation of the concept and the acquisition of word meaning is the result of a complex activity (i.e., the activity of operating on the word or sign) in which all the basic intellectual functions participate in unique combination.

Seed Dispersal

Part one of the research protocol involved seed dispersal. All students stated that the plant grew from a seed. The concept of seed, the word or sign, seed, was clearly understood by each age range of students. Seed is both an everyday concept and a scientific concept, according to Vygotsky. Seed is an everyday concept for several reasons. First of all, a seed is contextual in that the seed grew in an area on the ground, an observation made often as one walks across a lawn, and the seed grew into a plant in the soil using rain and sunshine. Second, in Piagetian theory, seed is a concrete concept, easily understood by students within the stage of development of third grade through college. Third, seed is an informal and spontaneous concept, known broadly by all populations and cultures. Fourth, seed is an experiential concept in that seeds are everywhere and a part of numerous foods. Students learn an everyday concept through their actual development and scientific concepts through their potential development. Everyday and scientific concepts interweave like the warp and the woof in fabric to form a true concept. The warp and the woof represent the underlying structure or base of construction. The warp threads run lengthwise at right angles and the woof threads run crosswise at right angles to form the warp and the woof. In Vygotskian fashion, the children have constructed a true concept of the word or sign, seed.

Pollination

Understanding across grade levels showed a continuum or zone related to actual development versus potential development, as indicated by the use of the terms, pollen and nectar. By continuum, Vygotsky meant that students can have more than one zone of proximal development and that concepts develop from one zone to the next dependent on their development and understanding.

All students indicated that flowers and pollinators needed each other for survival. Pollinators depend on flowers, and flowers need pollinators to scatter pollen. Of course, in the case of the extinction of one type of pollinator, another type of pollinator could pollinate a particular flower, as some students indicated in their responses. The younger students understood pollinator and flower interactions involving honey or nectar, yet could not formally define pollination. On the other hand, the tenth grade students and college students concluded that pollination was a means of getting pollen to flowers. Analysis of results showed that the term, pollination, is a formal or scientific concept, which is mediated by word or sign and constructed by students during formal instruction, not an everyday concept learned in an informal environment.

Food Chains

Food chain is a concept that may be learned informally rather than formally, and therefore an everyday as well as a scientific concept. The researcher showed students a photograph of a rabbit and asked what the rabbit ate. All students explained grass and other vegetation when probed. A rabbit is a concrete concept, familiar to everyone. When the researcher showed the students photographs of foxes and wolves, the subjects were not as familiar with their feeding habits, for foxes and wolves are not as commonplace in the environment. However, when the subjects were asked to complete a card sort of a food chain using foxes, grass, rabbits, and wolves, all students in the sample correctly arranged the cards to form the food chain. Understanding a simple, familiar food chain requires everyday or concrete conceptual thinking. A more complex food chain, which may involve a food web, requires both everyday and scientific concepts.

Some food chains are not as familiar to students, and some food chains actually involve food webs in which more than one animal feeds on others. The second food chain card sort presented in the protocol consisted of birds, cherries, insects, and hawks with the possibility of over-lapping responses and therefore requiring scientific conceptual thinking. The more common response was cherries, insects, birds, and hawks. Since both insects and birds often consume cherries, then the food chain card sort could have both insects and birds in the same location above cherries with hawks above birds and insects. Generalized food chains represent for the most part, thinking on a concrete or everyday basis and are within the zone of proximal development of students.

Vygotsky's Pyramid of Concepts

To explain the findings of the study in terms of a Vygotskian framework, Vygotsky's pyramid of concepts is illustrated, explained and then situated within the findings of this study. Vygotsky's pyramid of concepts involves three basic stages, each with distinct phases (Rieber & Carton, 1987). When confronted with a task an adolescent or adult could easily solve by forming a new concept or by connecting several relevant concepts, the younger child constructs a scope of isolated, unrelated, and unordered thoughts that are unified without sufficient internal foundation. The child's understanding is then a syncretism of thinking lacking connection, yet appearing similar to an adult's understanding. Children's objective connections will often correspond to established adult meaning, especially with everyday or concrete concepts, so that children and adults understand each other. Phases in the syncretic stage include, first of all, trial and error in which the child randomly connects objects or ideas through a series of probes that constantly replace one another until some meaning is apparent. In the second phase, spatial distribution, children group objects by general features or relatedness according to their perception of subjective connections of a concept. The third phase involves the child reducing united syncretic groups into a single meaning, but still lacking internal connections. Thus, the child still has an unordered collection of thoughts, not true meaning. Vygotsky's pyramid of concepts shows the development of concepts from childhood to adolescence. Figure 2 illustratesVygotsky's pyramid of concepts.

Vygotsky's Pyramid of Concepts

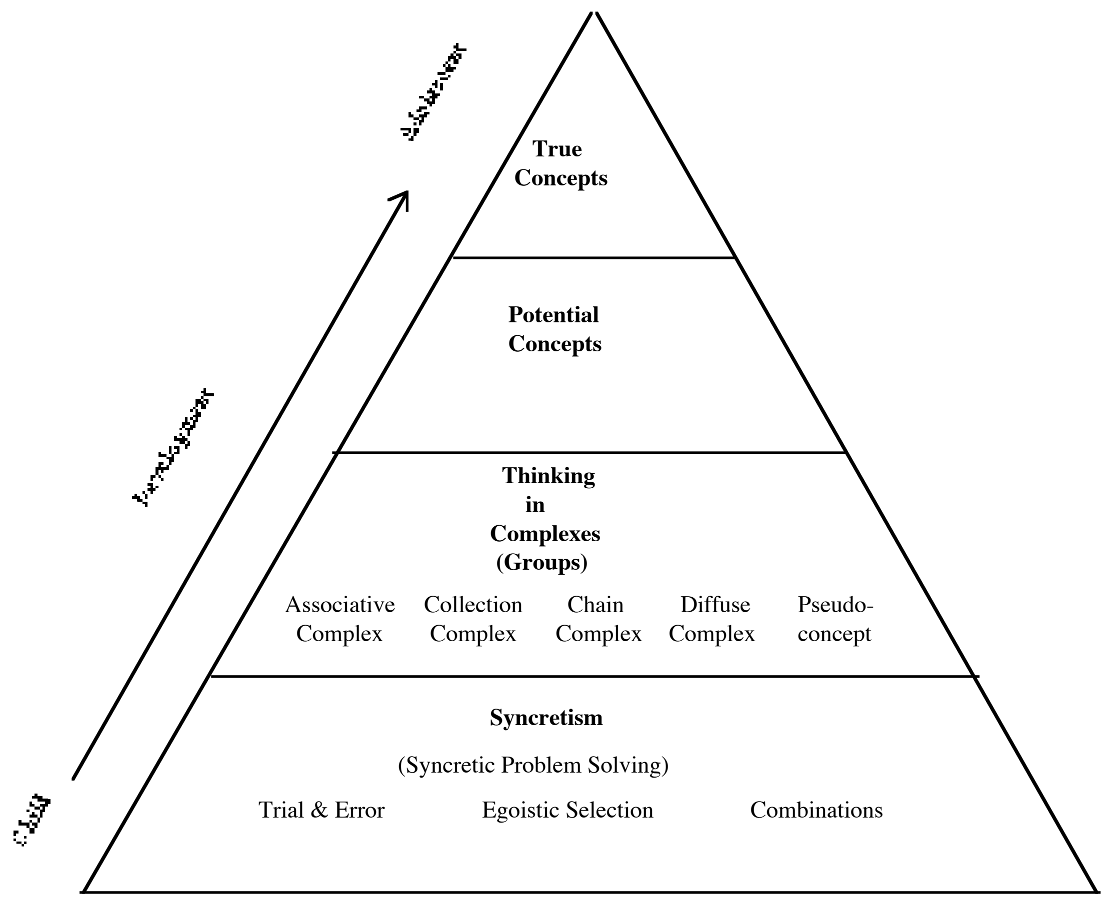

Figure 2. Vygotsky's pyramid of concepts illustrates the development of concepts from childhood to adolescence.

Thinking in complexes (Rieber & Carton, 1987) is the second stage of Vygotsky's pyramid of conceptual development. A child now groups objects according to objectively related connections, such as a family of objects. A complex is a concrete or everyday unification rather than a logical or scientific connection. Five basic types of complexes provide the basis or foundation for the child's thinking. Thinking in complexes means thinking concretely or informally rather than formally or scientifically. The first two complexes include an associative complex, linked on the basis of similarity, and a collection or association by contrast. A third type of complex is the chained complex, which consists of a collection of isolated elements with a unified theme. For example, students thought of the different methods of seed dispersal, but did not necessarily think of the methods as being classified or grouped strictly as seed dispersal. Fourth, a diffuse complex consists of incompletely defined or inconsistent connections of concrete objects. In seed dispersal, students did not connect seeds of different shapes as being designed for a different method of seed dispersal. The final form of thinking in complexes involves the pseudoconcept, a complex unification of a series of concrete objects based on simple association of characteristics. A child tends to think in complexes by grouping objects, such as by connecting blowing on a dandelion seedpod with seeds going everywhere, whereas an adult thinks scientifically, thereby forming a means of understanding.

The pseudoconcept serves as the link between the child's everyday and scientific thinking, between concrete and abstract thinking and unifies thinking in complexes and thinking in concepts. Next, the child's linking seed dispersal with dispersing agents without understanding the underlying reason of seed transport forms the potential concept. Finally, the student forms a true concept by recognizing the word meaning of dispersal, directing attention to the single feature of spreading seeds, synthesizing the isolated feature and symbolizing the abstract concept, then operating in the most advanced form of thinking of the sign or word dispersal that seeds have different shapes for different methods of dispersal (Rieber & Carton, 1987). A child's genetic development is the key to understanding, the basis of being capable of thinking scientifically or formally.

The final stage of children's conceptual development includes true concepts. Thinking in complexes may be thought of as the stage of potential concepts. Complexive thinking involves grouping objects according to a single similarity. The major distinction between thinking in complexes and thinking in concepts involves an understanding of different functional uses of a word. A word is a sign, and a sign can be used in different ways. Thinking in complexes involves applying a word to a single characteristic, whereas thinking in concepts consists of applying a word to different intellectual operations. For example, in this study when thinking in complexes, students think of yellow color as a characteristic of the word pollen. With conceptual development pollen becomes a substance that is transported by pollinators from flower to flower. Only during the transitional age of adolescence does thinking in concepts evolve. A concept is eventually severed from its concrete situation or perception and begins to be connected to an abstract and more comprehensive way of thinking. In the transitional age, students oscillate between using a word as a concept, while defining the word as a complex. Vygotsky's thinking in concepts involves a child's logical progression of thinking through the pyramid of concepts, vacillating from the general to the specific and from the specific to the general.

The data of this study indicated that younger children very definitely have an unordered collection of thoughts. For example, three of the younger children thought someone had planted the dandelion seed. Citing other methods of seed dispersal, such as wind or sticking to animals was not immediately clear in their thinking. Older students, especially college students, indicated conceptual understanding of seed dispersal without probing. Figure 3 shows Vygotsky's pyramid of concepts as applied to seed dispersal.

Vygotsky’s Pyramid of Concepts

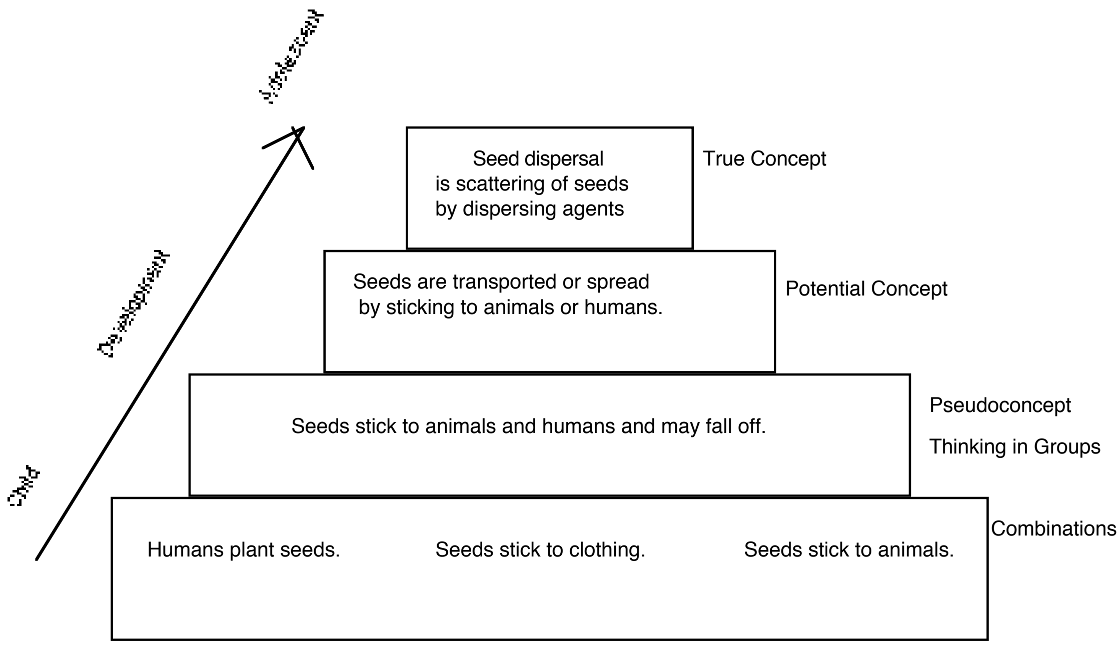

Figure 3. Vygotsky’s pyramid of concepts illustrates the development concepts from childhood to adolescence in seed dispersal.

The development of scientific concepts constructs a zone of proximal connections for the development of everyday concepts. Scientific concepts do not progress through a process of development, as do everyday concepts. Everyday concepts develop as the child links concrete objects with designated characteristics. For example, students connect honeybees on flowers as looking for food, honey, pollen, or nectar. Scientific concepts evolve through instruction. Eventually, the concreteness of everyday concepts merges into the abstraction of scientific concepts. According to Vygotsky, the verbalism or lack of concreteness of the scientific concept begins to change by the time a child reaches grade four. Piaget linked concept development at specific age ranges. In this study, third grade students usually lacked the scientific understanding found among students in grades seven, ten, and college. With each progression in grade level, as results showed, students had an enhanced understanding of scientific concepts. Students learn scientific concepts in completed form, not in heaps or complexes as with everyday concepts. A scientific concept cannot be learned by memorization, but by a child's thought processing at a given stage of development. Through conscious awareness, a transition to a higher mental state, scientific concepts are mastered. In learning scientific concepts, new structures emerge with the development of everyday concepts.

Developmental Pathways of Everyday and Scientific Concepts

Figure 4 shows the developmental pathways of children's everyday and scientific conceptual understanding as explained by Vygotsky. The zone of proximal development, the potential for learning, carries more significance for developing the intellect than a child's actual level of development. A child can learn a more complex concept in collaboration with a teacher, parent, or capable peer than alone. Learning a nonspontaneous, or scientific concept, requires construction using spontaneous or everyday concepts. Mastering scientific concepts influences the development of everyday concepts. A child's everyday concepts develop from the more elementary to the more complex, whereas scientific concepts develop from the more complex to the more elementary or lower level. The zone of proximal development links a child's understanding of lower, everyday concepts, to the higher, scientific concepts. The scientific concept represents potential development that has not yet matured. The scientific concept is not related to an object directly but is mediated by existing concepts. The development of a child's scientific concepts transforms a child's everyday concepts. A child first learns the general and then the specific. For example, a child learns the general concept of flowers, seeds, and pollinators before learning that specific kinds of flowers, seeds, and pollinators exist.

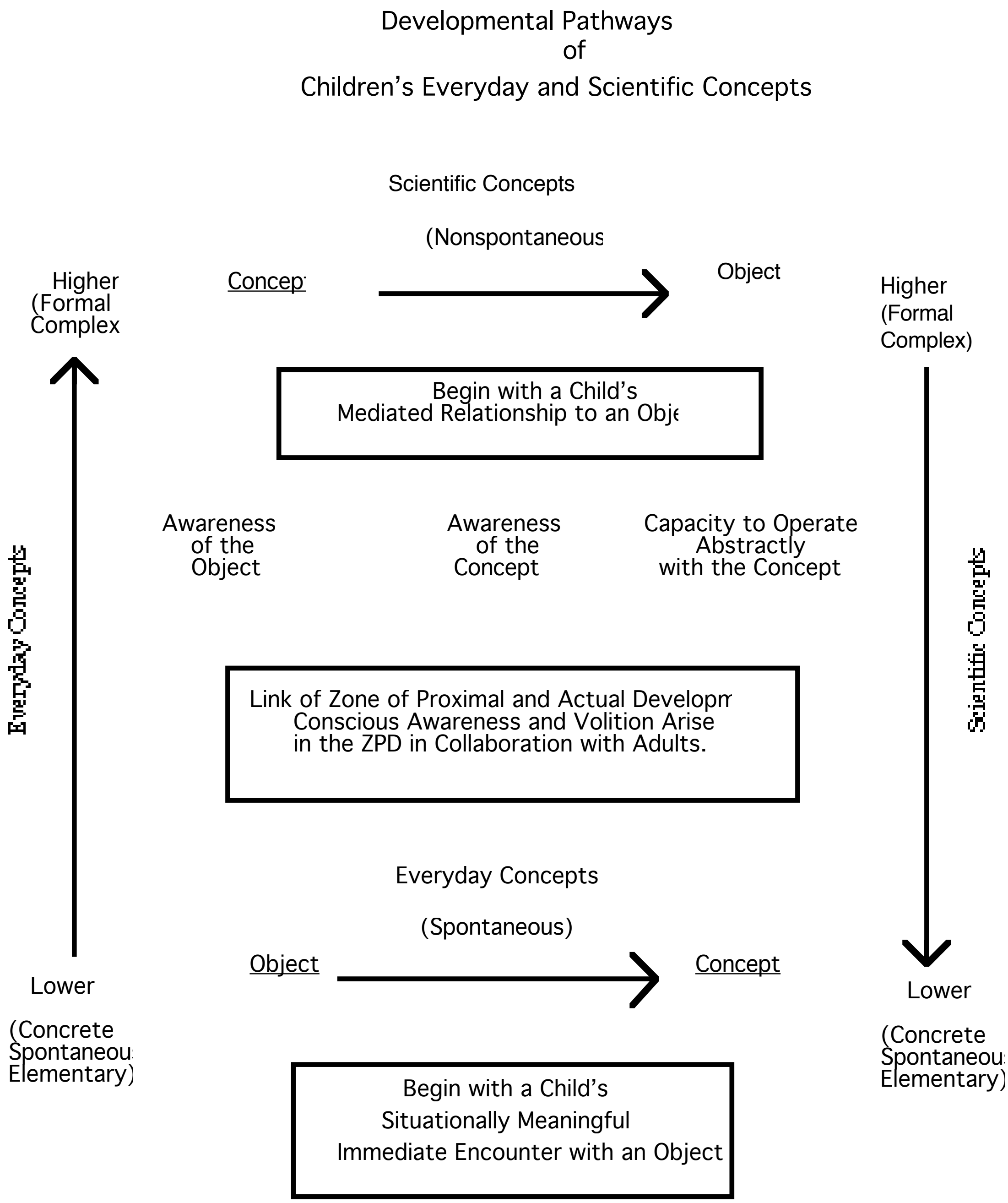

Figure 4. Scientific concepts and everyday concepts develop along opposite pathways and become linked by the zone of proximal development (ZPD) and actual development.

Figure 5 shows an application of students' conceptual development of pollination as applied to Vygotsky. The everyday concept is that flowers attract honeybees, and honeybees eat nectar. In the process of consuming nectar, the honeybees brush against pollen. The pollen attaches to the wings and body parts of honeybees or other pollinators. The honeybee then spreads pollen from flower to flower, which is pollination. Understanding of the scientific concept of pollination does not begin with the child's first or immediate encounter with a honeybee (an object), but with a mediated relationship to the object, following a system. The development of the scientific concept of pollination begins with conscious awareness and volition, and grows downward through the everyday concept into the domain of concrete, personal experience. In contrast everyday concepts begin with concrete, personal experience toward higher conscious awareness. The link between everyday and scientific understanding is the zone of proximal and actual development. As the data revealed, students generally noted that honeybees and other pollinators obtain food in some form from flowers, and then linked obtaining food with simultaneously brushing pollen on body parts to transfer to other flowers. Only a few students had developed scientifically and concluded that honeybees spread pollen from flower to flower.

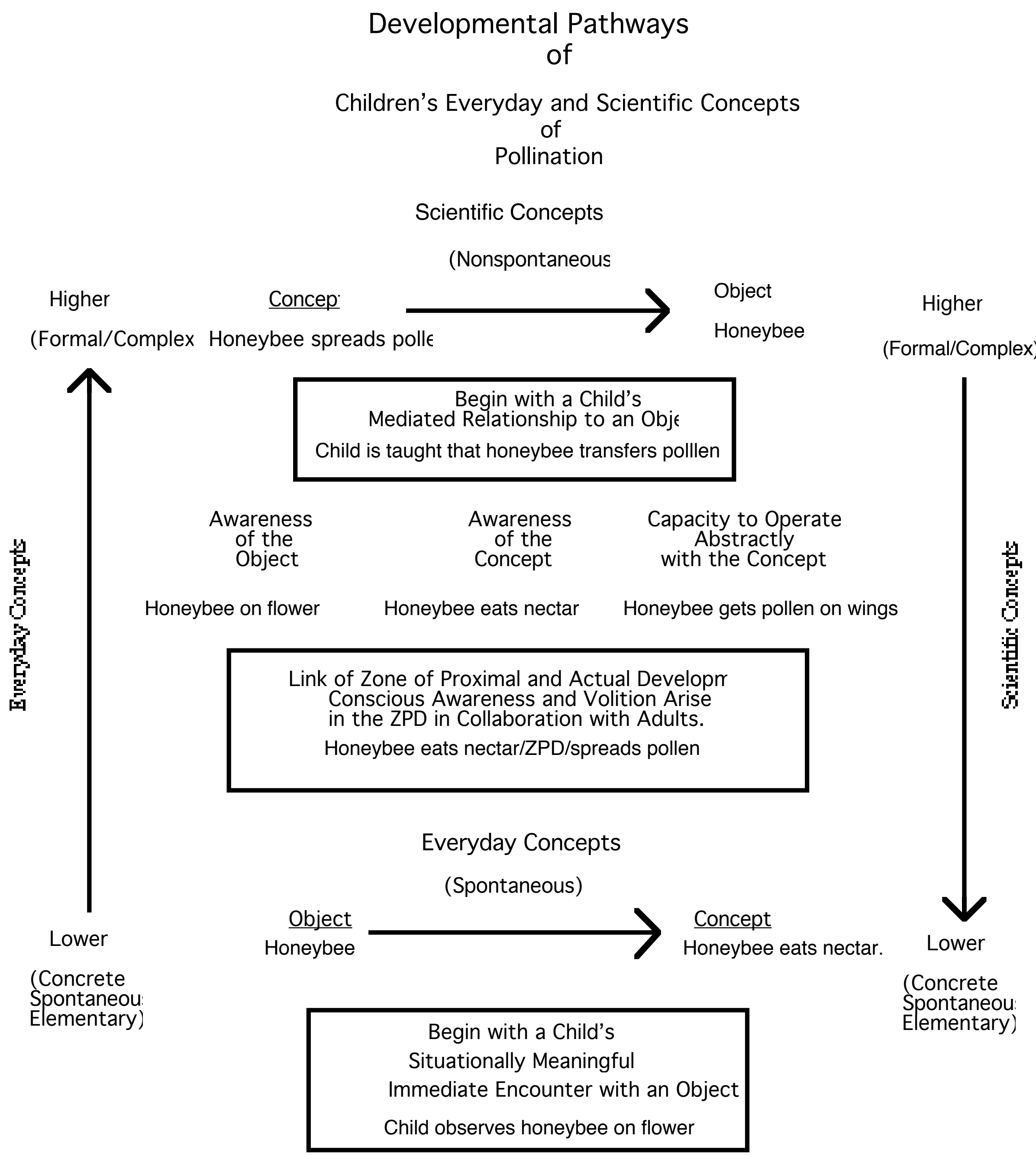

Figure 5. Scientific concepts and everyday concepts develop along opposite pathways and become linked by the zone of proximal development (ZPD) and actual development.

Conclusion and Significance of the Study

The significance of the study is that the research focuses on how students across ages or grade levels construct knowledge and develop an understanding of concepts. Teachers and those involved in preparing teachers to teach can gauge instruction based how children develop conceptual understanding across ages. Research by Vygotsky concluded that conceptual development begins in the earliest stages of childhood, undergoes changes in the transitional stages of pre-adolescence, and then develops into true concepts by adolescence (Rieber & Carton, 1987). The functional condition of the origin of a concept is considered in connection with a task or need in the thinking process connected to understanding or communicating and with completing a task during instruction which cannot be achieved without the formation of the formal concept (Rieber & Carton, 1987). Students have a level of understanding of a concept, and with formal instruction will develop a true concept by adolescence depending upon their zone of proximal development. The following is an illustration of conceptual development:

Everyday (Informal) Concepts →

Mediation by Word or Sign →

Construction of Scientific (Formal) Concepts

Across ages, that is, from

Grade 3 →

Grade 7 →

Grade 10→

College

Students vary in their conceptual development, yet develop an understanding of concepts in time. Depending upon the students involved, varying levels of understanding at one age proceed to a formal concept by adolescence. Of the three concepts studied, seed dispersal, pollination, and food chains, the data indicated that seed dispersal and pollination required learning at a higher level more than did food chains.

Limitations of the Study

Limitations of this cross-age study include the implications for using a convenience sample. Using a convenience sample is limiting because of the nature of the sample, especially since the students interviewed volunteered to participate in the study. Some students in a convenience sample could lack broader experience with the research topic, thereby limiting the quality of their responses to interview questions. Although the convenience sample consisted of students from both urban and rural settings, the population of the two groups was relatively small, yet varied. Students who attend the charter school may not be representative of the traditional student population in most schools. Students in the community center youth group were representative of the traditional school population.

Future Research

Future research will focus on exploring concept development using Vygotsky's theory of concept development, as well as further research on everyday and scientific concepts. Research on scientific and everyday concepts is limited in the literature. Applying concept theory on a larger scale to seed dispersal, pollination, and food chains, as well as related concepts, will assist with assessment of how students construct knowledge in the development of everyday and scientific concepts. Future research for teachers can focus on the continuum of the zone of proximal development, especially among the transition students in grades 7 and 10, when planning instruction. Knowing the ZPD means that classroom teachers can provide instruction for students in all grades and focus on conceptual understanding across grade levels.

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Appendices

Appendix A

Human Subjects

North Carolina State University

Institutional Review Board for the Use of Human Subjects in Research

Proposal Narrative

Subject Population

1. How many subjects will be involved in the research?

   Twenty-four (24) subjects will be involved in the research:

   6 elementary students (grade 3/age 8)

   6 middle school students (grade 7/age 12)

   6 secondary school students (grade 10/age 16)

   6 college students ((freshmen/age 18)

2. Describe how subjects will be recruited.

Students in elementary, middle and secondary schools will be recruited by obtaining permission from the top school administrator and asking him to recruit teachers who would be interested in volunteering to assist with student selection. Since many schools now have after school programs, I prefer to conduct the interviews after school so I will not disrupt classes. In order to assist the school administrator and teachers in giving me permission to conduct the interviews, I will give them copies of the interview protocol explaining that the research interviews are strictly for my research and will be kept confidential. I will also explain that their participation in my study may actually be of interest to them in the instructional process, for many schools use programs based on similar research. To obtain six students in each grade level to interview, I will send two copies of a letter home with students asking parents to read and sign the consent form. I will keep one copy of the informed consent form and send a copy to the parents with a letter stating that their child has agreed to the interview. On the day the interview is conducted for each subject, I will send a letter home to the parents with the child's signature and with my signature to indicate that the interview was conducted and to offer thanks for their assistance in my research study interviews.

College students will be recruited by asking for volunteers within an undergraduate biology class, or a convenience sample of volunteers, a method similar to how other students will be selected. I will work with an instructor, if applicable, to make sure students understand that the interview has no impact on their grades in the class.

Informed Consent Form

Research

North Carolina State University

Shirley M. Smith

Department of Mathematics Science and Technology Education

Dear Parents:

Dependent upon your prior approval, your child has been invited to participate in a research study involving science. The purpose of this study is to determine the source and extent of knowledge of representative K-college students pertaining to understanding food chains, pollination, and seed dispersal. The title of the study is A Cross-Age Study of Students' Understanding of Interdependency in Food Chains, Pollination, and Seed Dispersal Using A Constructivist Theoretical Framework. Principal investigator of the research study is Shirley M. Smith, Department of Mathematics Science and Technology Education (MSTE), North Carolina State University.

Ultimately, the research study is designed to fulfill the requirements for the researcher, Shirley M. Smith, to obtain a doctor of philosophy degree in science education with a minor in biology at North Carolina State University. The Department of Mathematics Science and Technology Education offers undergraduate and graduate degrees in teaching methodology and works with many schools in the Triangle. Your children may have been taught by graduates of the teacher preparation program.

Please be assured that if your child wants to participate and if you sign the consent form, the interview will not impact on your child in any way, except perhaps to bring awareness of the topics. The interview will simply aid the researcher in learning how students come to understand the science topics involved, which are food chains, pollination, and seed dispersal. Overall, the research is intended to add to the literature on how students learn.

Please note: I will obtain parent permission before gaining children's assent to participate.

Parental Signature

I have read the above information and understand the study. I agree to allow my child, ____________________________________, to participate in the science research interview, with the understanding that s/he may drop out at any time, or I may elect to have my child discontinue at any time without penalty.

____ _________________________

(signature) (date)

Thank you.

North Carolina State University

Institutional Review Board For The Use of Human Subjects in Research

Informed Consent Form

Verbal Consent Form for Younger Subjects

Title of Study, Principal Investigator, and Faculty Sponsor

You are invited to participate in a research study. The purpose of this study is to determine the source and extent of knowledge of representative K-college students pertaining to the concepts of food chains, pollination, and seed dispersal. The title of the study is A Cross-Age Study of Students' Understanding of Interdependency in Food Chains, Pollination, and Seed Dispersal Using A Constructivist Theoretical Framework. Principal investigator of the research study is Shirley M. Smith, and faculty sponsor is Dr. Glenda S. Carter, Department of Mathematics Science and Technology Education, North Carolina State University. Ultimately, the research study is designed to fulfill the requirements for the researcher, Shirley M. Smith, to obtain a doctor of philosophy degree in science education with a minor in biology at North Carolina State University.

Verbal Consent for Younger Subjects

Note: Verbal assent will be required for younger subjects who may not be able to read and sign a consent form. I will obtain parental permission before gaining children's assent to participate.

To the participants:

If you agree to participate in this study involving the concepts of food chains, pollination, and seed dispersal, you will be required to read and sign duplicate human subjects consent forms before participation in the study begins. The researcher will keep one copy of the signed consent form, and you will be provided the second signed copy of the consent form. Note: If a subject or legal representative is unable to read and/or understand the written consent form , as in the case of minors, the form will be verbally presented in an understandable manner and witnessed (with signature of witness). For the youngest subjects, verbal assent will be appropriate when obtained by the researcher through the process of reading a study "script" and including a signature line for the researcher to attest that the child verbally agreed to participate in the study. In addition, the parents of these children will receive a copy of the parental permission form to read and sign.

Younger Subjects (Age 12 and under)

Introduction

You are being given the opportunity to participate in a research study. In such a study, the researcher, the person conducting the study, is wanting to gather data in order to put together some new information. The information will be read, organized and written, and then published in some type of book to share with other people who may be interested, especially teachers helping students learn. The researcher usually does research to obtain a higher college degree.

Information

This study involves some information you may have learned in school, from your parents, from reading, or from a video or television The topics of the study are as follows:

1. Food chains--how all living organisms depend on green plants for food
2. Pollination--how all plants must be pollinated by insects, birds, bees, moths, bats, some other animal, or by the wind in order to survive from

year to year

3. Seed dispersal--How different seeds are made to land in a good place to grow into new plants

If you decide to participate in this study, I will ask you questions about science using cards, pictures, and perhaps some seeds to check for your understanding of food chains, pollination, and seed dispersal.

Procedure

Do you know what an interview is? Have you watched a person being interviewed on television? Can you name a person you have watched being interviewed? What was the topic of the interview? Can you tell me about the interview? How long did the interview last? Have you ever been interviewed? Would you like to be interviewed about the topics in this research study--about food chains, pollination, and seed dispersal? If you agree to help with the study, the interview will take about half an hour of your time, or maybe a little longer. We will go at your pace.

Risk, Confidentiality, and Compensation

Nothing about the interview will involve a risk to you in any way. The researcher will make sure you are comfortable doing the interview. You will probably enjoy having the researcher interested in what you know and how you learned what you know about food chains, pollination, and seed dispersal. The information you give will be kept confidential, (like a secret). You will not be given money for your participation, but you may have a small packet of seeds to show your parents.

Contact

If you have questions, you may call or e-mail me (Shirley M. Smith) at any time.

Participation

If you decide to participate in this study, your participation is based strictly on your decision. If you need a break or decide you do not want to be interviewed, then stop me, and tell me what you need to continue with the study, or if you prefer not to continue. No information will be used if you decide not to continue.

Consent

Do you understand how the interview will be conducted? Would you like to participate? Keep in mind that what you say about food chains, pollination, and seed dispersal will be kept confidential (a secret). The information will be stored securely, then shredded after the data is collected. If you understand the study, may I write your name in the space below along with my signature?

Thank you for helping with my research study today.

Verbal Consent for Younger Subjects

(Age twelve and under)

To Be Interviewed on the Concepts of Food Chains, Pollination, and Seed Dispersal

Parental Signature

I have read the above information and understand the study. I agree to allow my child, ________________________________, to participate in the science research interview, with the understanding that s/he may drop out at any time, or I may elect to have my child discontinue at any time without penalty.

____ ______________________

(signature) (date)

Thank you for your assistance. Shirley M. Smith

To the younger student (Age 12 and under):

You have been given permission by your parent(s) to participate in a research study.

If you understand the study and would like to participate, you may sign on the line below.

__________________________________ (student signature) _____________(date)

____ Print name

If your parent has signed a form and you say yes and/or sign the form above, then we will schedule an interview at a later time.

To the parents:

I, Shirley M. Smith, ___________________________ (signature) __________ (date) researcher, attest to the fact that your child, ___________________________, verbally agreed to participate in a research study involving the concepts of food chains, pollination, and seed dispersal. ___ 1 ___ 2 ___ 3 ___ 4 ___ 5 ___ 6

Consent for Subjects Twelve to Eighteen Years of Age

To be Interviewed on the Concepts of Food Chains, Pollination, and Seed Dispersal

North Carolina State University

Institutional Review Board For The Use of Human Subjects in Research

Informed Consent Form

Title of Study, Principal Investigator, and Faculty Sponsor

You are invited to participate in a research study. The purpose of this study is to determine the source and extent of knowledge of representative K-college students pertaining to the concepts of food chains, pollination, and seed dispersal. The title of the study is A Cross-Age Study of Students' Understanding of Interdependency in Food Chains, Pollination, and Seed Dispersal Using A Constructivist Theoretical Framework. Principal investigator of the research study is Shirley M. Smith, and faculty sponsor is Dr. Glenda S. Carter, Department of Mathematics Science and Technology Education, North Carolina State University. Ultimately, the research study is designed to fulfill the requirements for the researcher, Shirley M. Smith, to obtain a doctor of philosophy degree in science education with a minor in biology at North Carolina State University.

Information

This study involves some information you may have learned in school, from your parents, from reading, or from a video or television The topics of the study are as follows:

1. Food chains--how all living organisms depend on green plants for food
2. Pollination--how all plants must be pollinated by insects, birds, bees, moths, bats, some other animal, or by the wind in order to survive from year to year

3. Seed dispersal--How different seeds are made to land in a good place to grow into new plants

If you decide to participate in this study, I will ask you questions about science using cards, pictures, and perhaps some seeds to check for your understanding of food chains, pollination, and seed dispersal.

To the participants:

If you agree to participate in this study involving the concepts of food chains, pollination, and seed dispersal, you will be required to read and sign duplicate human subjects consent forms before participation in the study begins. The researcher will keep one copy of the signed consent form, and you will be provided the second signed copy of the consent form.

Note: If a subject or legal representative is unable to read and/or understand the written consent form , as in the case of minors, the form will be verbally presented in an understandable manner and witnessed (with signature of witness). For the youngest subjects, verbal assent will be appropriate when obtained by the researcher through the process of reading a study “script” and including a signature line for the researcher to attest that the child verbally agreed to participate in the study. In addition, the parents of these children will receive a copy of the parental permission form to read and sign.

Consent for Subjects Twelve To Eighteen Years of Age

to Be Interviewed on the

Concepts of Food Chains, Pollination, and Seed Dispersal

North Carolina State University

Institutional Review Board For The Use of Human Subjects in Research

Informed Consent Form

For older children who wish to participate:

I have read the above information and understand the study. I agree to participate and know that I may change my mind and drop out at any time.

I, ____ ___________ ____________

(Print name) (Age) (Grade)

______________________________________ _____________________

(Student signature) (Date)

agree to participate in the research study involving food chains, pollination, and seed dispersal.

I give my consent for my student/child to participate in the above research stud

____ Parent(s) signature

Thank you for your assistance.

___ 1 ___ 3 ___ 4 ___ 5 ___ 6

Consent for College Level Subjects

to Be Interviewed on the

Concepts of Food Chains, Pollination, and Seed Dispersal

North Carolina State University

Institutional Review Board For The Use of Human Subjects in Research

Informed Consent Form

For college students who wish to participate:

I have read the above information and understand the study. I agree to participate and know that I may change my mind and drop out at any time.

I, ____

(Print name)

____ ____________________

(Student signature) (Date)

agree to participate in the research study involving food chains, pollination, and seed dispersal.

Thank you for your assistance.

___ 1 ___ 2 ___ 3 ___ 4 ___ 5 ___ 6

Appendix B

Interview Protocol

A Cross-Age Study of Students' Understanding of Interdependency in Flora and Fauna Using

A Constructivist Theoretical Framework

Research Protocol

Interdependency in: Food Chains, Pollination, and Seed Dispersal

Dissertation Protocol

Dissertation protocol for interviewing subjects on the concepts of seed dispersal, pollination, and food chains:

Seed Dispersal

<u>Look at the photographs</u>:

1. How do you think the lone dandelion plant happened to grow here in this location?
2. Have you ever walked through some weeds and have seeds stick to your socks or jeans?
3. Have you ever seen seeds stick to an animal's fur?
3. Why do the seeds stick to your socks or jeans or to an animal's fur?
4. Why do you think the seeds are made so they will stick to humans or animals?
5. Is there any benefit for the seeds?
6. Do you know what a dandelion seedpod is?
7. Have you ever picked a dandelion seed pod and blowed on it? What happened?
8. What are each of the little cottony structures that blow in the wind?
9. Have you ever seen yellow powder on the ground or on your parents' cars?
10. What is the yellow powder?
11. Where was the yellow powder before it blew or fell on the cars?
12. What is the use of the pollen?
13. Have you ever seen seeds in water?

14. Where does the water take the seeds?

15. Do you know what is meant by seed dispersal?

Pollination

Look at the photographs of flowers and pollinators.

1. Why is the honeybee buzzing around the flowers?
2. What attracts the honeybee to the flowers?
3. Does the honeybee help the flower?
4. Does the flower help the honeybee in any way?
5. What is the hummingbird doing?
6. What about the bumblebee?
7. Does the bumblebee help the flower?
8. Does the flower help the bumblebee.
9. Look at the butterfly. Have you ever seen butterflies in your yard?
10. Where do you usually see butterflies? What are the butterflies usually doing?
11. Do you usually see butterflies in the sun or in the shade?
12. What kind of flowers do butterflies like?
13. Do butterflies help the flowers?
14. Do the flowers help the butterflies in any way?
15. Do you know of any other insects that like to fly around flowers?

16. Do you think other insects may help flowers?

17. What are some other insects that may benefit flowers?

18. Do you know what nectar is?

19. Where is nectar in flowers?

20. Have you ever heard of pollen?

21. Where is pollen in flowers?

22. Why is pollen important to the flower?

23. Can flowers and insects continue to live without each other?

24. What would happen if all the honeybees died?

25. What would happen if all the flowers died?

26. Do you know what pollination is?

Food Chains

Look at this diagram/picture of plants and animals representing a food chain/food web:

1. What do you think is happening?

2. What do you think the rabbit will eat?

3. Suppose no grass is growing. What else might the rabbit eat?

4. Suppose all the plants died. What would happen to the rabbit?

5. Note the picture of the fox. What does a fox eat?

6. Suppose all the rabbits went to another place or died. What would the fox eat?

7. Note the picture of the wolf? What does a wolf eat?

8. Suppose there are no foxes or rabbits. What would the wolf do?

9. Can you think of another food chain?

10. What is a food chain?

Appendix C

Card Sort Activity

Food Chain Card Sorts

Wolf Hawk Hawk

Fox Bird Bird Insects

Rabbit Insects Cherries

Grass Cherries

Appendix D

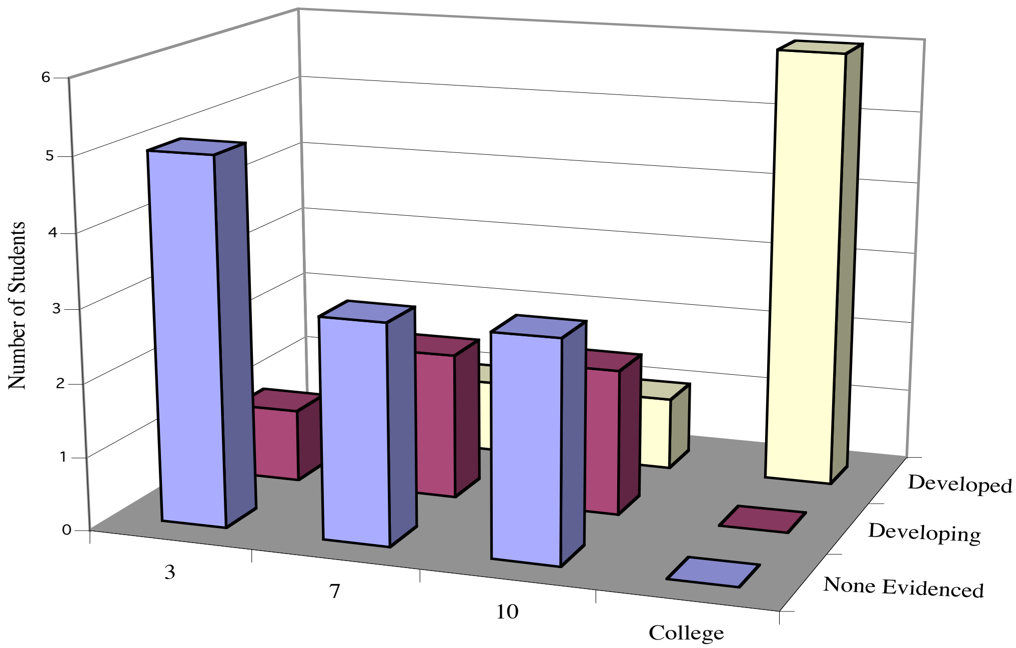

Figure 4-1 Summary of Seed Dispersal Conceptual Understanding

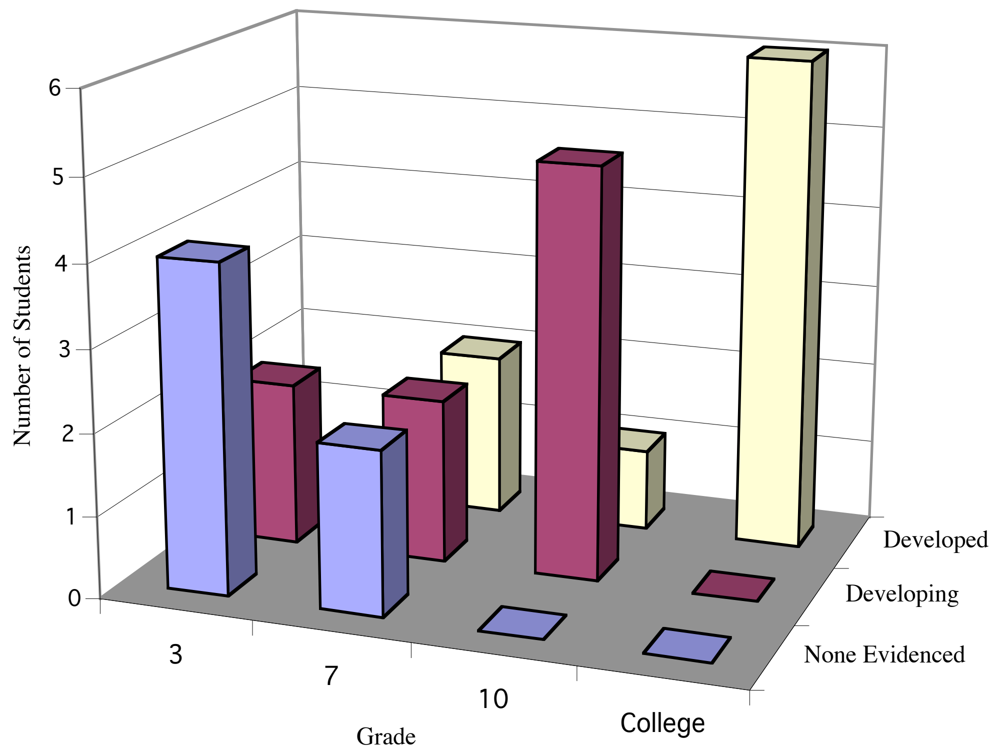

Figure 4-2 Summary of Pollination Conceptual Understanding

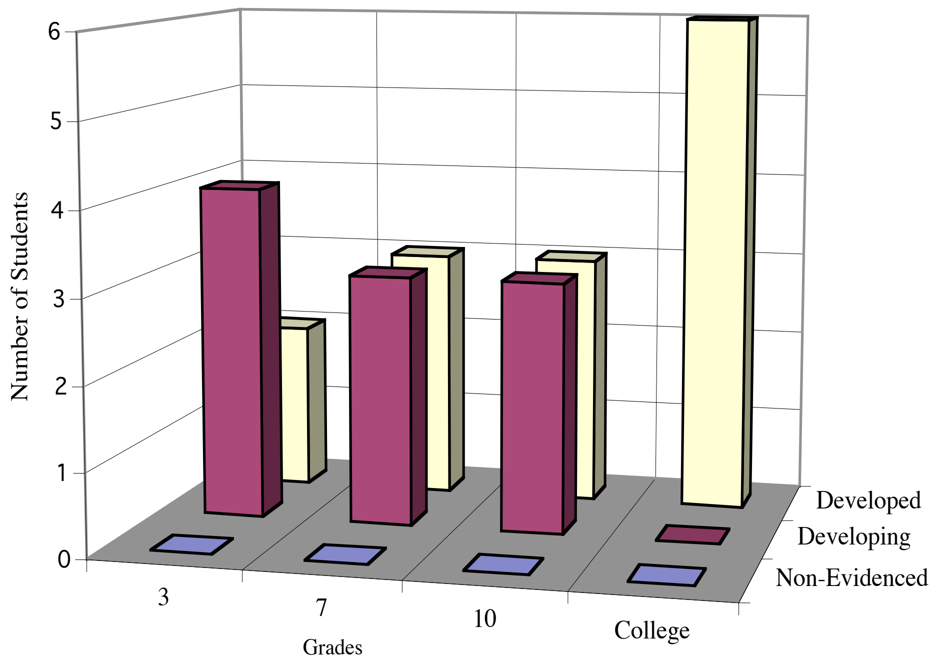

Figure 4-3 Summary of Food Chain Conceptual Understanding

Appendix E

Data Tables

Seed Dispersal

Table 1

Response to how lone dandelion flower grew in location in grass

Grade	Response
3-1	It “falled” off a tree. It grew. It grew from a seed.
3-2	It grew from seeds. Someone dropped the seed or it was carried by an animal or by wind.
3-3	It grew from a plant seed. Somebody planted a garden with a favorite flower seed.
3-4	You put seeds, and then it starts growing if you water it or if it rains.
3-5	Sprouted from a flower seed from water and light
3-6	Planted with a seed; people drop the seeds when they drive
7-1	Seed. Dropped from a tree
7-2	From seeds from other dandelions. The wind blew them or fell off.
7-3	Seeds. The roots, the sun.
7-4	Spread by seeds by a bird or by the wind.
7-5	Somebody planted it; it got there by rain and water
7-6	By being planted by nature or someone; the wind blew it
10-1	Seeds from another plant fell off and onto the ground, and it grew.
10-2	Seeds, sunshine, and rain
10-3	Someone planted it, or it just grew from seeds using water and sunlight.
10.4	Through pollination, from past seeds, maybe by wind
10.5	Someone planted the seed, or blown by the wind
10.6	Seeds that someone grew
C-1	Seed dispersal
C-2	Seeds carried by wind or animals.
C-3	Seeds carried by wind, birds, or rain.
C-4	Seeds. Root propagation.
C-5	The wind blew it from a dandelion seed pod.
C-6	From a dandelion seed, blowing in the wind or falling from a plant.

Seed Dispersal

Table 2

Questions: 1/Have you ever seen structures like these stick to your socks or jeans or to an animal's fur? 2/Do you know what the objects are called? 3/What did you do with the objects? 4/Do humans and animals stay in the same place or move around? 5/What happens to the seeds when people or animals move around? 6/Do you think the seeds will grow into a new plant in a new location and that humans and animals then represent a method of scattering seeds?

Grade	Response
3-1	1/Yes 2/Seeds 3/Threw them on the ground 4/Move 5/Seeds fall to ground 6/Yes
3-2	1/Yes 2/Seeds 3/Brushed them off 4/Move around 5/Seeds fall on ground 6/Yes
3-3	1/Yes 2/Sticks/seeds 3/Pick them off 4/Move to another yard 5/In the dirt 6/Yes
3-4	1/Yes 2/Seeds 3/Brush off 4/Move around 5/Land in soil 6/Yes
3-5	1/Yes 2/Seeds 3/People carrying them 4/Move around 5/Buried in the ground 6/Yes
3-6	1/Yes/No 2/Seeds 3/N/A 4/Walk around 5/Wouldn' get very far 6/Yes
7-1	1/Yes 2/Seeds 3/Fall to ground 4/Move, more places 5/Stick to ground and grow 6/Yes
7-2	1/Yeah 2/Prickles/seeds 3/Fell to ground 4/Move 5/Grow somewhere else 6/Yes
7-3	1/Yes/No 2/No 3/Get it off/throw in trashcan or ground 4/Move 5/Fall, grow 6/Yes
7-4	1/Yes 2/No 3/Travel to different places 4/Move 5/Transported and grow 6/Yes
7-5	1/Yes 2/No response 3/Take them off & throw on ground 4/Move around 5/Grow 6/Yes
7-6	1/Yes 2/Seeds 3/Get off clothing and put on ground 4/Move 5/Blows or falls off 6/Yes
10-1	1/Yes 2/No response 3/Pick them off 4/Move around 5/Seeds fall off 6/Yes
10-2	1/Yes 2/Seeds 3/Fell on ground 4/Move around 5/Fall on the ground 6/Yes
10-3	1/Yes 2/Seeds 3/Came off 4/Move around 5/Goingto come off 6/Yes
10-4	1/Yes 2/Sticks, seeds 3/Fell off 4/Move around 5/Fall off 6/Yes
10-5	1/No, yes 2/No 3/Come off 4/Walk around 5/Come off in another place 6/Yes
10-6	1/Yes, no 2/No response 3/Pull off clothing 4/Move around 5/Move 6/Yes
C-1	1/Yes 2/Seeds 3/Put in a different place 4/Move around 5/Go do different locations 6/Yes
C-2	1/Yes 2/Yes 3/Carry somewhere else 4/Move around 5/Take seeds elsewhere 6/Yes
C-3	1/Yes, no 2/Seeds 3/Fell off 4/Move around 5/Spread their seeds 6/Yes
C-4	1/No, yes 2/Seeds 3/Fell off and spread out 4/Move around 5/Spread out more 6/Yes
C-5	1/Yes 2/Spurs/seeds 3/Pulled off & dropped on ground 4/Move around 5/Go elsewhere 6/Yes
C-6	1/Yes 2/Seeds 3/Flick them on ground 4/Move around 5/For dispersement 6/Yes

Seed Dispersal

Table 3

Questions: 1/Have you ever blown on a dandelion seedpod, and if so what happened? 2/Have you ever seen seeds in the water and where did the water take the seeds? 3/Did the students show an understanding of different methods of seed dispersal?

Grade	Response
3-1	1/Yes, seeds go everywhere 2/Yes, to other places 3/Yes, scattering
3-2	1/Yes, fly and land on ground 2/Yes, to a stream bank in soil 3/Yes, summary
3-3	1/Yes, white stuff comes out 2/Yes, soil in water 3/Yes, methods
3-4	1/Yes, goes to different places 2/Yes, soil in water 3/Yes, scattering
3-5	1/Yes, white stuff flies off 2/Yes, everywhere 3/Yes, but didn't know formal term
3-6	1/Yes, seeds fall 2/No, to the ocean 3/Yes, but could not use term formally
7-1	1/Yes, seeds go everywhere 2/Yes, to other places where they grow 3/Yes
7-2	1/Yes, seeds went flying through the air 2/Yes, downstream on bank 3/Yes
7-3	1/Yes, little cottony structures fly off 2/Yes, to soil 3/Yes, somewhat
7-4	1/Yes, they flew around 2/Yes, to dry land 3/Yes, limited
7-5	1/Yes, blows off and flies everywhere 2/Yes, take in water to grow 3/Yes, but not formally
7-6	1/Yes, seeds blow everywhere & grow next spring 2/Yes, to the bank 3/Yes, but not formally
10-1	1/Yes, seeds went everywhere 2/Yes, to the shore to grow 3/Yes
10-2	1/Yes, seeds all fall off 2/Yes, float to bank & grow 3/Yes
10-3	1/Yes, stick to your clothes 2/Yes, underground 3/Yes, somewhat
10-4	1/Yes, seeds spread around 2/Yes, go into ground and grow 3/Yes, used formal term
10-5	1/Yes, white feathery things come off 2/Yes, under water 3/Yes, but not formally
10-6	1/No, no 2/No, under the sea 3/No, not formally
C-1	1/Yes, goes into a million different pieces 2/Yes, on banks & sand bars 3/Yes, formally
C-2	1/Yes, seeds fly through the wind 2/Yes, float somewhere to grow 3/Yes, formally
C-3	1/Yes, seeds blow in different directions 2/Yes, it would get planted 3/Yes, formally
C-4	1/Yes, spreads apart 2/Yes, catch on the edges of the banks 3/Yes, formally
C-5	1/Yes, seeds spread 2/Yes, downstream to the bank 3/Yes, formally
C-6	1/Yes, seeds went everywhere 2/Yes, on edge of stream 3/Yes

Table 4

Why are the honeybees buzzing around the flowers?

Grade	Response
3-1	To get honey
3-2	So he can get honey.
3-3	Because the honey flower has yellow stuff, which is pollen.
3-4	Because it has got honey.
3-5	Getting food, honey
3-6	Taking honey out
7-1	The pollen, the nectar, the honey
7-2	Pollen
7-3	Sucking all the juice and stuff out of it, honey.
7-4	To get honey
7-5	To get pollen and nectar from the flowers
7-6	To get nectar
10-1	To get pollen
10-2	To eat pollen.
10-3	Because it has honey and pollen.
10.4	To get nectar from the flowers
10.5	The yellow/pollen, to get food
10.6	Getting pollen, food
C-1	Pollen, nectar
C-2	They are actually picking up the nectar.
C-3	Pollen
C-4	Nectar, color, scent
C-5	Honey, nectar
C-6	Getting nectar and pollen.

Pollination

Table 5

Can flowers and pollinators live without each other? What is pollination?

Grade	Response
3-1	1/No 2/No
3-2	1/No 2/Has to do with pollen
3-3	1/No 2/No
3-4	1/No 2/No
3-5	1/Yes, some of them 2/No
3-6	1/I don't know. 2/No
7-1	1/No 1/No
7-2	1/No 2/No
7-3	1/No, nutrition stuff 2/No
7-4	1/No 2/No response
7-5	1/No 2//Yes, has to do with flowers and pollen
7-6	1/No 2/When they reproduce
10-1	1/No 2/No
10-2	1/No 2/No, I've heard of it.
10-3	1/No 2/No, I am not sure.
10-4	1/No 2/Yes, it's spreading of pollen from one flower to another (Learned in class, TV, books
10-5	1/No 2/Yes, getting pollen from flower to flower to reproduce, make different flowers
10-6	1/No 2/No
C-1	1/No, some pollinators could still live 2/Yes, a way to get pollen from flower to flower
C-2	1/Yes, some pollinators 2/Yes, taking pollen from one flower to another
C-3	1/I don't know, some other pollinators could take over 2/Yes, transfer of pollen then
C-4	1/No 2/Spreading the pollen, then fertilization of the egg
C-5	1/No 2/Getting pollen on the animal and to the female part of another plant
C-6	1/No 2/The transfer of pollen to a flower

Pollination

Table 6

Question: What is pollen, and where is pollen located?

Grade	Response
3-1	Don't know. In the middle of the flower.
3-2	Haven't heard of pollen. Don't know where it is located.
3-3	Yellow stuff. In the middle of the flower
3-4	Never heard of it. In the back or on the front of the flower
3-5	No response. In the middle of the flower
3-6	No. No response
7-1	Helps the plant grow. Is in the middle of the flower
7-2	Helps the flower in some way. Is in the flower
7-3	The green stuff. Is located in the trees
7-4	Yellow dust. On pine trees
7-5	Yellow dust on plants. Located in the middle of the flower
7-6	Yellow dust. Located in the center of flowers
10-1	Yellow powder located above the nectar in flowers
10-2	Food and helps flower grow. In the middle or all over the flower
10-3	Yellow dust located right down the middle of the flower
10.4	Yellow dust. Located inside the petals of flowers
10.5	Yellow dust. Located in the middle of flowers
10.6	Yellow dust. Located on the flowers
C-1	Yellow dust located in the flowers
C-2	Yellow dust, located on the outside of flowers
C-3	Yellow dust located around outside of flowers and deep in plants
C-4	Yellow dust on trees and flowers that fertilizes the egg
C-5	Yellow dust on trees or flowers located toward the center
C-6	Yellow dust on the trees or flowers used to produce seeds

Table 7

Interview Responses Question: Does the honeybee help the flower, and does the flower help the honeybee?	
Grade	Response
3-1	Yes; yes gives honey
3-2	Yes; yes, pulls something out of the flower; yes, gives food, honey
3-3	No; yes, gives honey and pollen
3-4	No; yes, gives honey
3-5	No; yes, gives food, honey
3-6	No; yes, gives food, honey
7-1	Yes, gives more pollen; Yes, gives it food—pollen, nectar
7-2	Yes, make honey out of pollen; yes, gives the honeybee pollen to make honey
7-3	No; yes, its food—honey
7-4	Yes; yes, seeds stick on it when leaving; gives food, honey
7-5	Yes; yes, takes pollen; pollen, nectar, and honey
7-6	Yes; yes, takes pollen and nectar, yes, takes pollen, pollen drops
10-1	Yes; yes, helps it grow, gives nectar
10-2	Yes; yes, helps by giving food,seeds
10-3	Yes; yes, gives food for it to produce honey
10-4	Yes, scatters pollen from flower to flower; yes, gives pollen and nectar
10-5	Yes, the yellow; yes, gives food
10-6	Yes, getting pollen; yes, gives food
C-1	Yes, by taking nectar and pollen to other flowers; gives pollen to make honey
C-2	Yes, picks up pollen with legs; yes, by providing nectar
C-3	Yes, transfers pollen and makes plant grow; yes, gives some liquid, nectar
C-4	Yes, spreads the pollen; yes, provides food in the form of nectar, honey
C-5	Yes, picks up stuff in center that drops on other flowers; yes, honey, nectar
C-6	Not sure, possibly by moving pollen; yes, provides nectar

Pollination

Table 8

Can flowers and honeybees live without each other?

(1) Can flowers and insects live without each other? (2) What would happen if all the flowers died? (3) What would happen if all the honeybees died?			
Grade	Question 1	Question 2	Question 3
3-1	No	No honeybees	No flowers
3-2	No	Pollinators could die	Flowers would die
3-3	No	Would have no garden	Flowers go back down
3-4	Yes/No	All pollinators die	Other bees come
3-5	Yes	All pollinators die	No response
3-6	I don't know	I don't know	I don't know
7-1	No	Flowers would die	Flowers would die
7-2	No	Flowers would die	Flowers would die
7-3	No	No food for honeybees	Nutrition stuff
7-4	No	All the honeybees would die	No transfer of pollen to other places
7-5	Yes	Bees would have no place to get honey	The plants would die
7-6	No	Bees wouldn't have anywhere to go	No honey, no flowers, no plants
10-1	No	Honeybees could die	Flowers would die
10-2	No	Bees & butterflies would die	Flowers would die
10-3	NA/No	All insects would die	Would be no honey in the flowers
10-4	No	All bees & butterflies would die	Flowers will die
10-5	No	Honeybees would die	I don't know
10-6	No	Insects would die	Would be no flowers
C-1	No	Yes	NA
C-2	I don't think so	NA	Flowers would have hard time reproducing
C-3	I don't know	A lot of animals would die	Other pollinators step in
C-4	No	All pollinators would die	Probably a lot less fertilization of flowers
C-5	No	Honeybees & other insects would have to find new food source	All the flowers that went to honeybees would die too
C-6	No	All insects & other pollinators would die	Flowers wouldn't have much to be reproduced

Table 9

Pollination Responses: Butterfly—Grades 3, 7. 10, College

Question: What is the butterfly doing? (Picture of butterfly on flower)	
Grade	Response
3-1	Getting honey
3-2	Trying to get food
3-3	Sitting on flower
3-4	Place to sit
3-5	Looking for food
3-6	Taking honey
7-1	Getting food, nectar, pollen
7-2	Eating—getting food
7-3	Food, honey
7-4	Honey
7-5	No response
7-6	Drinking nectar, getting pollen; drops pollen from flower to flower
10-1	NA
10-2	I don't know
10-3	Food
10-4	Take pollen
10-5	Not sure/no response
10-6	Food
C-1	Helping with pollination
C-2	Same as bees & hummingbirds; picks up pollen, nectar
C-3	Pollen & nectar
C-4	Drink nectar; pollinate flower
C-5	NA
C-6	Getting nectar; distribute the pollen

Table 10

Pollination Responses: Hummingbirds—Grades 3, 7, 10, College

Question: What is the hummingbird doing around the flower?	
Grade	Response
3-1	Getting honey
3-2	NA
3-3	Putting a seed in the flower; smelling the flower, pollen; getting the pollen
3-4	Drinking the honey
3-5	Picking seeds; getting food, insects, worms
3-6	Putting the honey in the flower; eating honey
7-1	NA
7-2	Eating pollen
7-3	Flower gives food to honeybee
7-4	Eating
7-5	Taking pollen from inside the plant
7-6	Getting nectar or maybe getting pollen
10-1	To get pollen
10-2	Eating the inside of the flower; probably food, seeds
10-3	Sucking honey, but not sure
10-4	Getting a little boost from the flower—nectar, pollen
10-5	Getting some food
10-6	Getting food
C-1	Pollen, nectar
C-2	Drinking nectar from the flower
C-3	Taking something out of the flower, some sort of lliquid
C-4	Drinking nectar; will touch pollen, stamens; spread pollen to pollinate flower
C-5	Getting food from the flower; does the same thing as the bee
C-6	Getting nectar; same as honeybee; gets pollen on its feathers and pollen gets on another flower

Table 11

Pollination Responses: Bumblebees—Grades 3, 7, 10, College

Question: What do you think the bumblebee is doing around the flower?	
Grade	Response
3-1	NA
3-2	Getting something to eat
3-3	Because the flower has pollen in it
3-4	Probably drinking the honey or eating
3-5	Picking seeds or looking for food
3-6	Sucking honey
7-1	NA
7-2	Will help the bumblebee
7-3	Feeds the bumblebee
7-4	Eating food
7-5	Looking for pollen; flower gives pollen, nectar, & honey
7-6	Getting pollen, bugs
10-1	Getting pollen; same as honeybee
10-2	Getting food from flower
10-3	Sucking honey; same as honeybee—flower gives food
10-4	Searching for pollen; getting nectar; spreads pollen from one plant to another
10-5	Flower gives food supply to help bumblebee
10-6	Getting pollen out of the flower
C-1	Pollen & nectar—same as honeybee
C-2	Picking up pollen & nectar—same as honeybee
C-3	Either pollen or nectar
C-4	Drinking the nectar; provides food; spreads pollen; pollinates the flower
C-5	Getting food from the center of the flower
C-6	Getting nectar from the flower; putting pollen from another flower

Table 12

Response to what rabbit consumes

Grade	Response
3-1	Grass, carrot.
3-2	The green stuff, leaves, grass, blueberries, carrots
3-3	The leaf, grass, pollen carrots, blueberries
3-4	The plants, grass, carrots
3-5	Grass, carrots, rabbit food, drink milk
3-6	Small food, carrots, grass, apples
7-1	Grass, flowers, carrot
7-2	Grass, plants, carrot
7-3	Carrots, leaves, grass
7-4	Grass, carrots, plants, berries, flowers
7-5	Leaf, grass, carrots
7-6	Grass, leaves, bugs
10-1	Lettuce, carrots, grass, plants
10-2	Grass and leaves
10-3	Grass, berries, carrots
10.4	Grass, insects, vegetables, apples
10.5	Carrots, vegetables, grass, plants
10.6	Grass, seeds from roots and stuff
C-1	Grass, plants, leaves
C-2	Green vegetation
C-3	Dandelions, grass, bushes
C-4	Vegetation, fruit, berries, plants
C-5	Grass and leaves
C-6	Grass, leaves, plants

Appendix F

Synonyms

For

Everyday Concepts Versus Scientific Concepts

Everyday Concepts	Scientific Concepts
Spontaneous concepts	Nonspontaneous concepts
Naive concepts	Schooled concepts
Gut knowledge	Scholarly knowledge
Informal learning	Formal learning
Generative	Encapsulated
Innate	Socio-cultural
Novice	Expert
Experiential	Logical
Prior knowledge	New Knowledge

Students' everyday knowledge of natural phenomena is also known as "alternative frameworks" or "interpretative models" rather than "misunderstandings" or "mistakes" Driver (1973). Driver also used the phrase, "children's ideas." Vygotsky used the terms everyday concepts vs. scientific concepts.