INQUIRY IN EARLY YEARS SCIENCE TEACHING AND LEARNING: CURRICULUM DESIGN AND THE SCIENTIFIC STORY

by

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ABSTRACT

Inquiry in school science, as conceived by the authors of the *Common Framework of Science Learning Outcomes K – 12*, is dependent upon four areas of skills. These are the skills of initiating and planning, performing and recording, analysing and interpreting, and communication and teamwork that map onto what Hodson calls the five phases of scientific inquiry in school science: initiation, design and planning, performance, interpretation, and reporting and communicating. This study looked at initiation in a multiage (Grades 1-3) classroom, and the curriculum, design tools, and inquiry acts believed to be necessary precursors of design and planning phases whether the inquiry in which young children engage is archival or laboratory investigation.

The curriculum was designed to build upon children's everyday biological knowledge and through a series of carefully organized lessons to help them to begin to build scientifically valid conceptual models in the area of animal life cycles. The lessons began with what is called benchmark-invention after the historical work of Robert Karplus and the contemporary work of Earl Hunt and Jim Minstrell. The introduction of a biological concept was followed by a series of exploration activities in which children were encouraged to apply the concept invented in the benchmark lesson. Enlargement followed. This was the instructional phase in which children were helped to establish scientifically valid relationships between the invented concept and other biological concepts.

The pre-instruction and post-instruction interview data suggest that the enacted curriculum and sequence in which the biological knowledge was presented helped the nineteen children in the study to recognize the connections and regularities within the life cycles of the major groupings of animals, and to begin to build scientific biological conceptual models. It is, however, argued that everyday biology, in the form of the person analogy, acts as an obstacle to biological understanding, and that the construction of scientific knowledge depends upon first hand experiences with organisms, as much as it does dialogical interaction, "acts of inquiry", and reflective exploration of multiple sources of information.

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Chapter One
Introduction and Overview

Inquiry has a long history in science education, and, like many factors tied to curricular myths, its prominence in pedagogy and curriculum documents has fluctuated. With the publications of the Council of Ministers of Education's (1997) *Common Framework of Science Learning Outcomes K to 12* in Canada and the National Research Council's (1996) *National Science Education Standards* in the United States, reform in science education is again synonymous with inquiry. Scientific inquiry is at the heart of science learning. Teaching school science involves students in inquiry-oriented investigations into authentic questions generated from experience. Teachers guide and facilitate inquiry-based learning. Learners in communities of inquirers develop abilities to think and act in ways associated with the standards of practice defined by the community of scientists.

One can not help but wonder if such a turn of events comes as a surprise to scientists, psychologists, and educators who contributed to the development of curriculum documents in the 1950s and 1960s and then witnessed their often rapid demise, and disbelief to others, like Philip Jackson, with a deep-seated interest in the public education of children. At the end of this unique curriculum reform movement when support of inquiry in school science was reported to be "more simulated than real in practice" (Welsh, Klopfer, Aikenhead, and Robinson 1981, p. 40), Jackson (1983) speculated that the inquiry/discovery approach to the teaching of science would fare no better in the future than it had in the recent past. His opinion seems not to have deterred the hundreds of people involved in the development of the *Pan-Canadian Science Framework* or the *Standards* and the science educators and teachers of school science who have adopted inquiry-based instruction and/or inquiry-based programs.

While the ability to inquire is considered to be a "critical aspect" of students' scientific literacy (1997, p. 6), the authors of the *Common Framework*, hereafter referred to as the *Pan-*

Canadian Framework, have not included a definition of scientific inquiry in their two hundred sixty page document. Under the heading "teaching of science", scientific inquiry is one of three "broad areas of emphasis… in which students address questions about the nature of things, involving broad exploration as well as focused investigations" (1997, p.8) that require certain specifiable skills. There are skills of questioning, identifying problems, developing preliminary ideas and plans, gathering evidence by observation, manipulating materials and equipment, examining information and evidence, processing and presenting data, interpreting, evaluating, and applying results in collaboration with others (p. 12).

In contrast to the Canadian framework, the American *Science Education Standards* (NRC, 1996) provides definitions on pages 2, 23 and 214, and the changes in emphasis brought about by the teaching and content standards are made explicit in charts on pages 52 and 113. The focus is implementing inquiry as an instructional strategy, or strategies, for the purpose of developing "understanding, ability, values of inquiry and knowledge of science content" (p. 113). The points reiterated again and again are that "the *Standards* call for more than science as process" (p. 2) that "learning science is something students do, not something that is done to them" (p. 20), and science is argument and explanation rather than getting an answer through exploration and experiment (p. 113).

Champagne, Kouba, and Hurley (2000) report that the *Standards* document does not distinguish between scientific inquiry, inquiry, investigation, and experimentation. (The same conclusion could be reached in reading the *Pan-Canadian Framework*.) In response to this finding, they propose a separation between scientific inquiry, as "practiced by natural scientists", and science-related inquiry, that is "practiced by adults and students who are science literate" (p. 450). In the latter category they place archival investigation, experimentation, and laboratory investigation. Archival investigation, more commonly identified as "research", is described as an inquiry for the gathering of information by any means other than empirical. That is, through language- and graphics-based media. Experimentation is "an inquiry for the purpose of testing a hypothesis that derives from a scientific theory." It "must meet the rigid methodological requirements of the scientific community" and is, therefore, encountered in secondary school science (p. 452). Laboratory based investigations are fair and unbiased tests. The questions they are designed to answer do not relate to theory, and "[t]he answer does not provide any insights into the nature of the natural world" (p. 452). This would include product testing and experimenting as described by Bentley, Ebert, and Ebert (2000). Unlike Champagne and her colleagues, Bentley and his associates include trial and error searches for solutions, documenting, prediction testing, reflecting, generating models, and inventing as additional forms of investigating. None of these six types of investigations, however, meet the established requirement for fair testing and can not be considered a laboratory-based form of science-related inquiry. They could, however, contribute to the precursor (initiating) and planning phases of inquiry.

It is the initiating phase in which the investigator identifies a problem, develops preliminary ideas, and formulates a question or hypothesis (see de Boo, 1999; Hall, 1998; Hodson, 1999; Lehrer, Carpenter, Schauble, and Putz, 2000; Metz 2000; Pearce, 1999; Tolman and Hardy, 1999; among others). All forms of inquiry pass through this phase, and whether the urge to know and understand is a consequence of exploration in the classroom, lessons, experiences in the world, information read and/or heard and/or seen, personal needs, or interactions with others, the desired result is always a good question. Good questions, according to Elstgeest, are productive questions, "because they stimulate productive activity" . He writes:

> A good question is the first step towards an answer; is a problem to which there is a solution. A good question is a stimulating question which is an invitation to a closer look, a new experiment or a fresh exercise. The right question leads to where the answer can be found: to the real objects or events under study, there where the solution lies hidden (1985, p.37).

Jelly, who interprets this to mean that productive questions "promote science as a way of working" (1985, p. 45), claims that "many of the questions children ask spontaneously are not productive starting points for science" (p. 44). This is as much a consequence of the learner's motive for asking a question, as it is the kind of question posed (*eg*.: philosophical questions, comments expressed as questions, interrogative questions, questions that satisfy the urge to name and to identify, rhetorical questions, complex how and why questions that originate in wonder, and the like). When questions stem from curiosity and a desire to go beyond current understanding, to bridge the gap between existing knowledge and apprehending something new, they are not often expressed in a form that is investigable (Harlen, 1996). The general consensus among science educators is that the skill for formulating inquiry questions must be modeled in an environment conducive to question asking by the learner (see Fraser and Tobin, 1998; McGilly,1994; Minstrell and van Zee, 2000; Mintzes, Wandersee and Novak, 1998c; among others). It is believed that the teacher has an important role in demonstrating and bringing to the attention of the learner the discursive characteristics and "conventions that characterize science (which can be a mystery to novices)" (Tobin, 1998, p. 142). Of particular interest here is the motive for asking and how one supports "information seeking questions" (Lindfors, 1999) that are useful in the development of ideas, scientific concepts, and conceptual models.

In her description of children's inquiry as "a language act in which one attempts to elicit another's help in going beyond his or her present understanding" (1999, p. ix), Lindfors makes it clear that inquiry arises in what one knows (p. 92). As such, "inquiries can only belong to the inquirer" (p. 57). They reflect not only a personal interest and a unique engagement, but also the inquirer's private knowledge, experience, and momentary "puzzlement" (p. 96). For this reason, she writes: "It makes sense that inquiry utterances are imperfectly formed – even downright messy sometimes, for they are acts of going beyond, not acts of having arrived" (p. 63).

Many teachers begin an inquiry with brainstorming sessions or inquiry conferences where children are given the opportunity to say what they know about a topic and would like to find out. Others may follow a guided or open exploratory activity or series of activities with class meetings where questions arising from observations are shared. In either case, the child knows that questions are expected. The questions, whether productive or unproductive, will arise from personal knowledge and mental models that may have little in common with scientific knowledge and scientifically valid conceptual models. One wonders what the consequences might be if the inquiries of children, that is, the language acts described by Lindfors, were a feature of a curriculum designed to help build conceptual models where science-related inquiries, either archival- or laboratory-based investigations, occurred at the end of the activities for model building.

The curriculum designed for the study integrated the conditions believed to be necessary for children to begin to learn and apply scientific knowledge and for children to begin to know and utilize the methods and processes by which scientists generate valid and reliable knowledge. These conditions, reviewed in Chapter Two, are presented from two perspectives. The chapter begins with the science education literature and ends with the literature of a group of language educators who perceive curriculum as collaborative inquiry.

Chapter Three is both a short history of inquiry in North American science education and a critical review of the science curriculum development projects funded by the National Science Foundation in the United States from the mid-1950s to the mid-1970s. Many of these projects were dismissed as being too loosely organized, beyond the reach of the average learner, and outdated with respect to developments in the philosophy of science. If inquiry learning and teaching is to be successful this time around, it seems prudent to familiarize one's self with the curriculum programs and the failings attributed to them.

The research design of the study and the methods by which data were collected and analyzed are presented in Chapter Four. The chapter also includes a description of the instructional context and the strategies embedded in the curriculum and lessons that were intended to make thinking visible while fostering the development of conceptual models.

The results of the study are arranged in three sections in Chapter Five. The first section is a summary of the children's responses to pre-instructional interview questions. The second focuses on the teaching and learning associated with the instructional lessons. The third presents a synopsis of the children's responses to post-instructional interview questions. The results are discussed in Chapter Six along with the implications they have for teaching and research focused upon the education of young children.

CHAPTER TWO
LITERATURE REVIEW

CHILDREN'S LEARNING OF SCIENCE (FROM THE PERSPECTIVE OF SCIENCE EDUCATORS)

North American school science is again in the midst of reformation. One does not have to look deep into the education literature to uncover the concerns[1] driving this reform or to determine the direction in which reform agenda hope to move science education at early, middle, and senior years levels.[2] In light of the economic, political, and social anxieties motivated by decreases in science enrollment and consistent declines in the achievement and performance of students, it would be reasonable to attribute contemporary reform efforts to a shift in curriculum ideology: those periodic displacements that influence curriculum thought and emphasis. Research studies over the past two decades on children's science and science learning indicate, however, that students have little understanding of the scientific ideas that they encounter in school settings regardless of the ideological stance, the curricular orientation, and the best efforts of accomplished teachers and creative program developers (see Anderson and Lee, 1997; Anderson, Holland, and Palinscar, 1997; Driver, Leach, Scott, and Wood-Robinson, 1994b; Gardner, 1991; Mintzes and Wandersee, 1998b; Pfundt and Duit, 1994; Reif, 1990; Wood-Robinson, 1995; Yager, 1995; among others). If, as teachers of science, our goal is to promote generative and functional understanding of the theories, models, laws, principles, concepts, and facts of science, as well as scientific processes, scientific methodologies, and the epistemology of science, changes in our approaches to the teaching of this discipline should be undertaken.

Novel terms and phrases[3] drifting into the science education literature suggest that pedagogical change is being informed by cognitive science, cognitive psychology, social psychology, cultural anthropology, sociolinguistics, and the history, philosophy and sociology of science. Learning science is no longer considered by science educators to be (1) the sole consequence of the development of cognitive structures and operations in isolation of other cognizant human beings; (2) passive acquisition of the products of science whether hierarchically organized within a framework and presented to the learner or transmitted as discrete and incoherent propositions; or (3) the elimination of everyday conceptions and their replacement with accepted scientific knowledge. At the time of this writing, the conditions associated with meaningful[4] learning in science can be represented by the following four statements:

1. The development of scientific understanding is a process of personal knowledge construction that is mediated by one's social and cultural milieu.
2. The development of scientific understanding is dependent, to a great extent, on what the learner already knows.
3. The development of scientific understanding occurs at the level of concept acquisition, the construction of new knowledge, and the evaluation and modification of existing knowledge.
4. The development of scientific understanding is contingent on an awareness of the epistemological aspects of science and how scientists come to know.

As will be seen, these conditions are inexorably intertwined; the defining statements blur at the periphery and are by no means discrete.

CONDITION #1: The development of scientific understanding[5] is a process of personal knowledge construction that is mediated by one's social and cultural milieu (Appleton, 1997; Brown, Collins and Duguid, 1989a; Champagne and Bunce, 1991; Driver, Asoko, Leach, Mortimer, and Scott, 1994a; Forman, Minick, and Stone, 1993; Hogan, 1999; Howe, 1996; Inagaki, 1992; Lucas, 1993; O'Loughlin, 1992; Pea, 1993; Resnick and Klopfer, 1989; Roth, 1995; Ryder, 1993; Shapiro, 1994; Solomon, 1987 and 1993; von Glaserfeld, 1989; Vygotsky, 1978; White, 1988; Wood, 1988; Zuckerman, Chudinova and Khavkin,, 1998; among others).

From the moment children begin to use sensory-motor operations to interact with the environment, they develop ideas about the objects, events, and phenomena encountered. Interaction alone, however, does not lead to intellectual development or the formation of scientific concepts. According to Day, French, and Hall, "[c]ognitive abilities are neither magically generated in social isolation, nor innately given, nor passively assimilated. Rather, nascent skills emerge that are refined as children actively participate in supportive contexts that are structured by others" (1985, p. 36). This requires that "[c]hildren grow into the intellectual life around them" (Vygotsky, 1978, p. 88). A life in which Bruner and Haste contend, language, interaction, and cognition are interwoven. They write:

> Through language, the child is quickly aided in her entry into *culture*: its metaphors, its kinds of explanation, its categories, and its ways of interpreting and evaluating events. These are not *invented* by the child; they are the common currency of the culture, the framework that determines the boundaries of the child's concepts (1993, p. 2).

This common currency, the procedures, symbol and sign systems, practices, and concepts of a culture, can only "be learned and perfected in interaction with those who already possess and practice them" (Wood, 1988, p. 213). As a consequence of the nature of this interaction, cognitive abilities are socially transmitted, socially constrained, socially nurtured, and socially encouraged (Day *et al.*, 1985).

Drawing upon empirical evidence from social psychology and studies of school science instruction, Champagne and Bunce (1991) suggest that the ineffectiveness of traditional teaching techniques in developing scientific understanding is a consequence of three failures. These are (1) failing to appreciate the knowledge that students bring to lessons, (2) failing to provide opportunities for students to make this personal knowledge explicit, and (3) failing to promote teacher-student and student-student interactions that make possible the communication and evaluation of ideas in a manner congruent with the nature of science. With respect to the discourse practices advocated in the third failure, a growing group of educators is arguing for a congruence that is much more comprehensive than that envisioned by Champagne and Bunce (see Abrams, 1998; Anderson, Holland, and Palinscar, 1997; Bereiter. Scardamalia, Cassells, and Hewitt, 1997; Bloom, 1998; Brown and Campione, 1994; Driver *et al.*, 1994a; Gil-Perez and Carroscosa-Alis, 1994; Lemke, 1990; McGinn and Roth, 1999; Roth, 1995; Wells, 1995; among others). These educators conceive of science learning as a personal and social process of enculturation. The objective, whether explicitly or implicitly articulated, is the acquisition ("appropriation") of what Gee (1991) calls a secondary discourse or identity kit. Children are to be socialized into the discourse practices of the scientific community, by doing science and talking science rather than hearing science (Pea, 1993). In this manner, they are introduced to scientific language, concepts, symbols, standards, and conventions (*i.e.* accepted ways of seeing, thinking, formulating questions, supporting knowledge claims, proposing explanations, negotiating meaning, acting, and using language). Following Vygotsky (1978, p. 28), Gee's identity kit is perceived as being a set of tools that will come to guide, determine, and dominate action. As such, Wells (1995, p. 9) writes, "rather than as ends in themselves, they [the artifacts and practices of the dominant cultural tradition] are mastered for their functional utility," where functional utility is interpreted as meaning, "for purposes of action and inquiry".

CONDITION #2: The development of scientific understanding is dependent, to a great extent, on what the learner already knows (Bruer, 1996; Bruner, 1990; Claxton, 1993a; Cleminson, 1990; Donovan, Bransford, and Pellgrina, 1999; Driver, Guesne, and Tiberghein, 1985; Driver, Leach, Scott, and Wood-Robinson, 1994b; Duckworth, 1987; Duit, 1991; Fensham, Gunstone, and White, 1994; Glaser, 1991; Glynn and Duit, 1995; Osborne and Wittrock, 1983; Osborne and Freyberg, 1985; Resnick, 1983; Tobin, Tippins, and Gallard, 1994; Wandersee, Mintzes, and Novak, 1994; among others).

Studies of students' understandings of scientific knowledge reveal that learners enter into formal science instruction with attitudes, habits, and a diverse set of conceptions concerning objects and phenomena (Claxton, 1993a; Cleminson, 1990; Driver *et al.*, 1994b; Duit ,1991; Eylon and Linn, 1988; Gardner, 1991; Glynn and Duit, 1995; Harlen, 1997; Lucas, 1993; Osborne, 1984; Pfundt and Duit, 1994; Russell, 1993; Wandersee *et al.*, 1994; among others). These conceptions are constructed, in and out of school settings, from personal knowledge gleaned from private, trial and error sensory experiences, predicaments, or needs (*cf.* Osborne's "gut dynamics) and symbol- and language-mediated social experiences (*cf.* Osborne's lay dynamics). Research reveals that these conceptions can be, and often are, inconsistent with the concepts, terms, principles and conceptual models presented in school science (*cf.* Osborne's physicists' dynamics). As such, they can either impede or facilitate learning events that are intended to help students come to understand the natural world as it is presently known by the scientific community (Black and Lucas, 1993; Champagne and Bunce, 1991; Chinn and Brewer, 1998; Duit, 1991; Eylon and Linn, 1988; Gelman, 1999; Gilbert, Osborne, and Fensham 1982; Glynn and Duit, 1995; Gunstone, 1988; Inagaki, 1992; Mintzes and Wandersee, 1998b; Novak, 1988; Wandersee *et al.*, 1994; among others).

Whether conceptual change occurs in response to data that is either new, anomalous, unexplainable, awkward, consistent, or matching, Chinn and Brewer (1998) propose that the outcome of school science experiences will be a consequence of five factors, or "critical barriers" to adopt Hawkins' (1978) terminology. These are (1) the entrenchment of prior conceptions, (2) the quality of the background knowledge that comes into play, (3) the processing strategies employed, (4) conceptions about the nature of science, and (5) the origin, quality, kind, and explicitness of "input information". To this list, Bloom (1998) would append the learner's underlying beliefs (*e.g.* anthropocentrism, anthropomorphism, zoomorphism in biological contexts) and personal connection to the subject matter (emotions, values and aesthetics, for example, "I like these little worms." and "[I]t's disgusting, when you feel them."). This, of course, presupposes that the student is committed to learning something: that the benefit of acquiring, manipulating, and transacting knowledge is worth the cost (Claxton, 1993a, pp. 57-59 and 1993b, p. 196; see also, Anderson and Lee, 1997; Pintrich, Marx, and Boyle, 1993; among others); and that personal worlds of family, friends, schooling and science are more or less congruent with respect to values, beliefs, expectations, and behaviours – that students can move from one setting to another with little adjustment and reorientation (Costa, 1995; see also, Hogan, 1999).

Regardless of the nature of the change that teaching, the classroom microculture, reflection, and social pressure may bring about, it is believed that learners must be made aware of their ideas, and that science curricula and instructional strategies must somehow take extant knowledge into account (Black and Harlen 1993; Hewson 1981; Mintzes and Wandersee 1998b; Osborne and Wittrock 1983; Osborne, Bell, and Gilbert, 1983; Stinner, 1995; Tobin *et al.* 1994; Wheatley 1991; among others). Simply teaching the right conception is not enough. Duit and Treagust, for example, maintain that "[l]earning science is only successful if learning pathways are designed to lead from certain facets of preinstructional knowledge towards the science perspective" (1998, p. 19). This is not to suggest that teaching and learning strategies should be activities that promote and foster the addition of new knowledge, by accretion, to existing gut and lay science. The conviction, which has a long history in education, is merely to recognize that an understanding of the learner's current knowledge is the most appropriate starting point for instruction.

Contemporary cognitive theory makes clear that thinking and learning are knowledge dependent (Resnick, 1989): what is known is used to link, interpret, and explain new information, ideas, and experiences (Resnick and Klopfer, 1989). As Ogborn writes, "Nobody has thought of any other way of thinking a new thought and so of imagining a new entity or process, than that of adapting a familiar idea, of passing from the known to the unknown" (1995, p. 10). The consequence, made obvious by research studies in cognitive science and of children's conceptual structures, is that "different students may learn different things from the same learning experiences" (Cleminson, 1990, p. 441; see also, Chinn and Brewer, 1998; Duit, 1991; Gilbert *et al.*, 1982). It is the learner's idiosyncratic network of meanings and understandings in conjunction with Claxton's cost-benefit analysis of deciding how to learn that determine, to a large extent, the outcome of school science instruction and the understanding that will be constructed.

CONDITION #3: The development of scientific understanding occurs at the level of concept acquisition, the construction of new knowledge, and the evaluation and modification of existing knowledge (Anderson *et al.*, 1997; Anderson and Roth, 1989; Black and Harlen, 1993; Bransford and Vye, 1989; Collins, 1997; Driver *et al.*, 1994a; Duschl and Hamilton, 1998; Fensham *et al.*, 1994; Glynn and Duit, 1995; Hatano and Inagaki, 1992; Johansson, Marton, and Svensson, 1985;

Lind, 1999; Linn and Muilenburg, 1996; Minstrell, 1989; Mintzes and Wandersee, 1998b; Nussbaum,1989; National Resource Council, 1996; National Sciences Resources Center *et al.*, 1997; Posner, Strike, Hewson, and Gertzog,1982; White, 1995; Wittrock, 1994; among others).

CONCEPTS

Concepts are commonly defined as general ideas, thoughts, or notions (American Heritage Dictionary, 1992). According to Pines (1985, pp. 108-110), concepts are cognitive entities, the furniture of the conscious mind, the substance of thought, and the systems of relations conventionally labeled with words through which human beings experience reality. In education, the definition can be more or less circumscribed. Bruner, Goodnow, and Austin, for example, suggest that a concept is "the network of inferences that are or may be set into play by an act of categorization" (1956, as cited in Black and Harlen 1993, p. 210). Eggen and Kauchak expound upon this definition when they write, "concepts are categories, sets, or classes with common characteristics", where characteristics are a concept's defining features (1996, p. 70). They propose that concepts are constructed through a process that involves discriminating between essential and nonessential characteristics, specifying the essential characteristics, and generalizing from these characteristics. As a consequence, concepts, like democracy, with many defining features and/or characteristics that are not concrete and observable and, thus, more troublesome to make distinct, tend to be the most difficult to learn.

In school science, each term encountered can be thought of as a concept, and a majority of these are complex with hard-to-specify characteristics (*e.g.* gravity, light, force, electricity, floating, alive, adaptation, evolution, photosynthesis, mineral, rock, equilibrium, matter, atom, change, order, system, and the like). Nevertheless, science as we know it would be impossible without the cognitive processes of categorization (concept invention, concept modification, and concept identification, that is, deciding when the use of a particular concept is appropriate) and transformation (using concepts to make predictions, to formulate ideas for action, and to solve problems) (Black and Harlen, 1993). Moreover, mental life, according to Smith and Medin would be utterly chaotic. They write,

> If we perceived each entity as unique, we would be overwhelmed by the sheer diversity of what we experience and unable to remember more than a minute fraction of what we encounter. And if each individual entity needed a distinct name, our language would be staggeringly complex and communication virtually impossible. Fortunately though, we do not perceive, remember and talk about each object and event as unique, but rather as an instance of a class or concept that we already know something about... Concepts give our world stability. They capture the notion that many objects or events are alike in some important respects, and hence can be thought about and responded to in ways we have already mastered. Concepts also allow us to go beyond the information given: for once we have assigned an entity to a class on the basis of its perceptible attributes, we can then infer some of its non-perceptible attributes... In short concepts are critical for perceiving, remembering, talking, and thinking about objects and events in the world (Smith and Medin, 1981 as cited in Black and Harlen, 1993, p.209-210).

MENTAL AND CONCEPTUAL MODELS

Black and Harlen (1993) believe that in the teaching of school science, more effort is spent on the process of transforming concepts and conceptual models[6] than categorizing objects or events as examples of particular concepts. As a result, although children can use a familiar concept appropriately once its relevance to a problem has been determined, their concepts are generally restricted to the narrow range of contexts in which they were learned, and their networks of inferences are often underdeveloped (vague and loosely interrelated), fragmented, and poorly organized. Unlike the expert with diverse relational understanding who recognizes that a given problem is a case of a particular concept with attributes and implications that connect it with other pertinent concepts, children in a comparable circumstance will wander through their collection of mental and conceptual models trying to use each in the manner of an unsystematic trial and error investigation (also see Anderson, 1989; Glaser, 1991; Hunt and Minstrell, 1994; McGilly, 1994; and Prawat, 1989; Yates and Chandler, 1991; among others). Reif sees this as an example of nominal knowledge (*cf.* Whitehead's inert knowledge) as opposed to functional knowledge: "it may be recalled and verbalized, but cannot be flexibly applied…"(1990, p. 95).

While this may be as much a consequence of life experiences as the enacted curriculum in school science, it is always an enacted curriculum underpinned by a particular curriculum emphasis.[7] The emphasis may or may not give genuine significance to any number of the following: children's intuitive ideas and conceptions about the physical world; authentic science experiences; decision making and the solving of novel problems; the development of fundamental skills and processes (metacognitive/self-regulatory as well as scientific); the nature and structure of the discipline; the ideas accepted by the scientific community; the social embeddedness of thought and individual development (others, including peers, as cognitive resources, not impediments to learning), and the organization of children's knowledge in mental and conceptual models.

For many science educators, including Anderson (1989), Arnold and Millar (1996), Glynn and Duit (1995), Hewson, Beeth, and Thorley (1998), Hunt and Minstrell (1994), Linn and Muilenburg (1996), Mintzes and Wandersee (1998a), Nersessian (1991), Ogborn, Kress, Martins, and McGillicuddy (1996), Prawat (1989), Raghavan, Sartoris, and Glaser (1998), and Reif (1990), restructuring of conceptual frameworks is central to developing scientific understanding. More generally, the construction of conceptual models is considered to be "at the heart of the instructional exchange" (Resnick, 1988, p. 47). The aforementioned authors urge teachers of school science to help children to build and refine conceptual models and to develop relations among other pertinent conceptual models by means of explicit instruction, modeling, and opportunities to practice both categorizing and transforming. If this is not done, Duit advises, the huge mental step that is necessary for learning a totally new way of viewing phenomena scientifically can not be made by the learner; in which case, "an approach starting from the students' conceptions and experiences will definitely fail" (1991, p. 76).

The methods by which teachers of school science instruct, model, and enable children to apply and modify the fundamental concepts, features or relations constituting conceptual models will depend upon the particular view of learning embraced and the type of learning environment and instructional experiences believed to foster and promote changes in learners' conceptual frameworks. As Duschl and Gitomer make clear, the goal is always the learner who consistently makes use of conceptual models that are scientifically valid and consistent with disciplinary knowledge, not merely personally viable. They write:

> An effective way of conceptualizing what is involved with the restructuring process of conceptual change is to consider Hanson's notion of observation or "seeing." In his classic book *Patterns of Discovery* (1958), Hanson distinguishes between "seeing as," which is observation that occurs without the benefit of appropriate background knowledge, from "seeing that," which involves observations with appropriate background knowledge. In a sense, the task science educators face is to take individuals who are "seeing as" and help them become "seeing that" observers. This is a simplistic but nonetheless accurate version of conceptual-change teaching and learning (1991, p. 841).

CONCEPTUAL CHANGE AND CONCEPTUAL CHANGE TEACHING

An analogy between the learning of disciplinary knowledge (*i.e.* conceptual change) and theory development in science has been discussed by a number of educators in an attempt to understand how choices are made between alternative views, models, or theories. The perception put forward is that the development of scientific understanding involves a process of constructing and reconstructing personal conceptions, theories, and/or models that reflects early philosophical models of theory restructuring within science (Anderson and Smith, 1987; Carey 1985; Confrey 1990; Duit, 1991; Duschl and Gitomer 1991; Duschl and Hamilton, 1998; Gilbert and Swift, 1985; Glynn, Yeany, and Britton,1991; Hodson, 1988; Novak 1993; Nussbaum 1989; Posner *et al.* 1982; Villani, 1992; Vosniadou and Brewer 1987). These are Thomas Kuhn's periods of normal science and revolutionary science and Imre Lakatos' changes to the soft core of a research programme and abandonment of the programme's hard core of theoretical commitments.

Borrowing from Kuhn's and Lakatos' epistemological principles, new information either is related or fails to be related to the learner's conceptual framework. The former type of change, occurring within or between existing knowledge structures, is described as weak restructuring, or assimilation. New knowledge enriches and elaborates current conceptions without significantly modifying the learner's guiding assumptions. The latter type of change is described as radical restructuring, strong restructuring, or accommodation. New information is incompatible with existing conceptions, conflicts with guiding assumptions, and can not be incorporated within one's cognitive framework. Hence, if scientific understanding is to be developed, the conceptual model (not the mental model) of the learner must be replaced or exchanged. That is, existing knowledge is incommensurate with new knowledge.

Much of the work on conceptual change has been focused upon determining the conditions and processes that encourage accommodation/strong restructuring (see Posner *et al.*, 1982). To this end, a number of instructional strategies have been developed (see Scott, Asoko, and Driver, 1992). Whether these are derived from internalist or externalist perspectives of science (Duschl and Hamilton, 1998), the general consensus is that "conceptual change is only rarely a sharp exchange of one set of meanings for another" (Fensham, Gunstone, and White, 1994, p. 6). Learners hold on to their intuitive conceptions with an almost stubborn tenacity. Mental models, as a consequence, remain highly resistant to change even when confronted with cognitive dissonance (see Anderson and Smith, 1987; Driver, Guesne, and Tiberghien, 1985; Eylon and Linn, 1988; among others). Given the reality of this resistance, Hodson asks, why it should be otherwise: "If an idea has served its purposes well in the past there will be little urgency to replace it" (1999, p. 242).

"Gut" and "lay" conceptualizations of science phenomena have proven to be effectual means of understanding the world and living a good life in it. But, as Claxton makes clear, this commonsense understanding is "largely built on an out-of-date science" (1993b, p. 197). We have learned to see the world as it is understood by those around us and the diffusion into culture of scientific knowledge is slow. This particular set of circumstances is perceived by Macbeth, as a conundrum to science education. He writes:

> It seems that, for science, what must be taught cannot easily be found elsewhere, and, worst, what *is* found elsewhere inveighs against the aims of science instruction. While we might admit various shades of understanding for a short story, understanding the relationship of light to vision seems to admit but a very few scientifically accountable ways of speaking. By analogy, we can say that there is no equivalent of "West Side Story" for Boyle's Law, and that there isn't, delivers special burdens to the science student, teacher, and the curriculum designer. The resistance to change that science educators find in their students' naïve and incommensurable ways of seeing and thinking about the natural world is thus both an obstacle and distinguishing mark for science education. In may also signal a decisive departure from any version of naïve induction that holds that science can be found in ordinary experience (2000, p. 234).

Different means to resolve Macbeth's conundrum have been proposed (see Brown and Campione, 1994; Cobern, 1996; Driver *et al.*, 1994a; Hewson *et al.*, 1998; Glasson and Lalik, 1993; Glynn and Duit, 1995; Hodson, 1999; Linn and Muilenburg, 1996; Macbeth, 2000; Mintzes and Wandersee, 1998b; Monk and Osborne, 1997; O'Loughlin, 1992; Pea, 1993; Pintrich, Marx, and Boyle, 1993; Roth, 1995; Scott and Driver, 1998; White, 1995; among others). Collectively, these more recent models for conceptual change teaching have several features in common that distinguish them from former "cognition-only" models that have been referred to as cold, isolated, and rational – "driven solely by logic and scientific findings" (Pintrich *et al.*, 1993). The features that tend to appear, though rarely in the same combination, are the following: social and dialogical interaction; metacognitive discourse; mediated, scaffolded instruction (cognitive apprenticeship); anchored instruction (situated cognition/learning); and authentic science practice. Although these new approaches could be perceived as an attempt to generate "intraindividual links" between contextual, motivational, and cognitive components of learning as described by Pintrich, Marx, and Boyle (1993) or an ecological approach to learning in formal settings, the change is more consequential than either of these two signify. It exemplifies what Sfard (1998) calls "a remarkable foundational shift"[8], and in this case two shifts are involved.

Scientific Communities and Situated Cognition

The first shift is informed by historical and sociological accounts of the development and restructuring of scientific knowledge. It emanates from philosophical writing that embeds social circumstances of cognitive activities in explanations of knowledge use and change. Duschl and Hamilton suggest that the apsychological view communicated "has challenged perspectives about what should count as the basic unit for doing science" (1998, p. 1051). Scientific objectivity is no longer perceived as being a characteristic of individual scientists who accept, reject, or ignore new ideas and make choices between competing views on the basis of evidence and the cogency of arguments. Rather, scientific objectivity is distributed among various members in scientific communities and located within what Longino (1990; 1994) refers to as "group dynamics". To qualify as knowledge, which indicates that consensus within the scientific community has been achieved, there must be publicly recognized forums for the criticism of all relevant perspectives, publicly recognized standards of evaluation, and changes to beliefs and theories in response to critical discourse, not as a consequence of political or economic power (Longino, 1994, pp. 144-145).

The second shift originates in cognitive psychology, specifically investigations of the relations between perception and cognition, and language and thought. These studies show "an inextricable link" between contextual constraints and the acquisition/construction of knowledge. The performances of learners are believed to vary from context to context because competence is a function of the context in which the learning activity is set (Butterworth, 1992, pp. 1 and 12), and the content and context of thought are considered inseparable from reasoning (Mercer, 1992). Claxton describes it thus:

> What we know, the 'knowledge' and 'skill' that we acquire, remain in general tied to more or less precise specification of when, where, why and how we acquired it. And these sorts of 'adverbial' tags serve to indicate the new situation within which the 'nouns' and 'verbs' of content and process will be retrieved and reactivated. Even content and process, so-called 'declarative' and 'procedural' knowledge cannot be dissociated: our know-how is associated with a sense of what to apply it

> to: our know-that comes back to use with its own packages of processes and operations for using and expressing it (1993b, p. 191).

Claxton goes on to suggest that generalizing and recontextualizing, the ability to see the relevance of something known to something new, must be taught. It is a matter of experience as opposed to effort, intelligence, or depth of understanding.

According to Anderson, Reder, and Simon, (1996), the degree to which knowledge is bound to a specific context is determined not only by the nature of instruction but also the way the material is studied. The following are thought to impair the transfer of knowledge from one context to another: information presented in a single context (limited representation and limited instruction on shared symbolic components across multiple contexts); studying the information, presented in a single context, in the context of its acquisition (limited opportunity for generalizing and limited opportunities for metacognition and self-regulation); abstract instruction bereft of specific concrete examples (limited opportunities to practice and apply learning in a variety of tasks); and presenting declarative knowledge without procedural and strategy knowledge (limited exposure to the cues that signal the relevance of a particular concept, problem solving tactic, or skill) (Anderson *et al.*, 1996; Butterworth, 1992; Duschl and Hamilton, 1998; and Hatano and Inagaki, 1992).

Learning in school science has been described as content-, context-, and task-dependent (see Claxton, 1993a and b; Collins, Brown, and Newman, 1989; Hennessy ,1993; Lucas, 1993; Cognition and Technology Group at Vanderbilt, 1990; among others). The educators cited below suggest that a goal of adaptive expertise (knowing when to access and how to apply what is known) will require significant changes to curriculum, teaching strategies and classroom interactions. These changes include, but are not limited to, the following: active/reflective exploration of multiple sources of information (Hatano, 1993); various representations (Champagne, Gunstone, and Klopfer, 1985); numerous encounters with interesting and relevant problems (Stinner, 1995; Wells and Chang-Wells, 1992); diverse contexts (Minstrell, 1989;

Stinner and Williams, 1993); frequent dialogical interaction (Hatano and Inagaki, 1992); coached practice (Bransford and Vye, 1989), and time to consider prior meanings, to explore new ideas, to link new ideas to other existing ideas, to construct new meanings (Carr, Barker, Bell, Biddulph, Jones, Kirkwood, Pearson, and Symington, 1994; Hodson, 1988).

CONDITION #4: The development of scientific understanding is contingent on an awareness of the epistemological aspects of science and how scientists come to know (Carr *et al.*, 1994; Desaultels and Larochelle, 1998; Driver *et.al.* 1994a; Duschl, 1990; Hewson *et al.*, 1998; Hodson, 1988; Matthews, 1990, 1991,1994, 1998; Osborne, 1995; Scott *et al.*, 1992; Smith, 1987; Taylor, 1998).

The importance of the epistemology of science in science education has resurfaced with the emergence of social constructivism. In the late nineteen eighties and early- to mid-nineteen nineties, discussions of the dimensions of an education in science and of the aims of school science invariably included a component focused on the processes by which scientific knowledge is generated (see Duschl, 1990; Hodson, 1985 and 1990; among others). Ogborn (1988), for example, in his map of science, suggests that there are five aspects of science that should flow as red threads through science education beginning in the earliest years of formal schooling. These "lines of development", stated as questions, are the following (questions and statements in parentheses are Osborne's (1995, 1996) reformulations):

1. What are things like? What are they made of? (What do we know?) – the ontological line (the ontological question);
2. How does it work? (Why does it happen?) – the line of causation (the causal question);
3. How do we know? How can we find out? – the epistemological line (the epistemological question);
4. What does it mean? (How can we communicate these ideas?) – the communication line (the communicative question); and
5. What can we do? (What can we do with our knowledge?) – the pragmatic question (the technological question).

Duschl (1990) contends that science programs and school science curricula that fail to address Ogborn's epistemological line paint an incomplete picture of science. A picture that Osborne suggests is "the intellectual equivalent of giving a child a hammer without the nails" (1995, p. 928). A clear and well-defined understanding of the scientific community's methods for producing knowledge and ensuring the reliability and validity of knowledge claims is necessary if learners are to have a notion of what a scientific explanation is, an appreciation of the status of ideas/explanations, and the capability to distinguish between justified and unjustified beliefs – the foundation of the rationality of science. Without this understanding, science is merely a compilation of tenets that is no more valuable than any other way of knowing. Rather than being "made-by-the-world", it is construed as "a way of world-making" (Osborne, 1995, p. 931).

To counteract the relativism such a position generates (see Harding and Hare, 2000), it is essential that teachers of science ask more than the familiar ontological questions associated with the teaching/learning strategy known as KWL, specifically: "What do you/we know?"; "What do you/we want to know or find out?" Learners' ideas must be elicited and made explicit in the context of the development of the topic, not as "a one time event at its start" (Hewson *et al.*, 1998, p. 204). These ideas should then be discussed and epistemological questions posed, namely: "Why do you believe you are right?"; "What is your evidence for believing?"; "How would you justify that view?"; and "How do you know?" (Osborne, 1995, 1996; *cf.* "Aron's questions" coined by Stinner, 1992). It is at this point that Hewson and his colleagues (1998) suggest that activities be introduced for "raising" or "lowering" the status of particular ideas. This may involve providing examples, applying the explanatory ideas in other circumstances, giving different ways of thinking about them, linking the explanations to other ideas, exploring unacceptable implications, considering experiences that ideas are unable to explain, and pointing out inadequacies. When this happens, "students have the opportunity of choosing between different ideas on the basis, not of who said them, but how good an explanation each provides" (Hewson *et al*, 1998, p. 203; *cf.* Hodson, 1988).

The history and philosophy of science (see Arons, 1991; Hodson, 1988; Klopfer, 1969;

Matthews, 1990, 1994; Stinner, 1996, 1998; and Stinner and Williams, 1993, 2000; among others), Ernst Mach's genetic method (Matthews, 1991); Schwab's (1960, 1962a) "inquiry into inquiry", and authentic scientific inquiry (open-ended problem solving) have much to offer the learner with respect to the processes by which scientific knowledge is constructed within the constraints of the universe in which we live and to the standards/criteria by which constructions are judged to be credible, valid, and better than competing claims. Notwithstanding, Ogborn (1994, as cited in Osborne 1996, p. 67) and Hodson (1988) caution science educators and teachers of school science not to confuse the construction of new scientific knowledge (the philosophy of science) with "old science" learned in the classroom (pedagogy). As Hodson explains: "...sound curriculum development depends crucially on a careful consideration of the relationship between the nature of science and the nature of learning. However, it would be a mistake to assume that this relationship is simple and direct..." (p.36). This is particularly true of practical work in school science where the way that science is practiced is thought to be the best way to teach and learn, in which case, doing science is often confused with learning science. Kirschner (1992), attributes this situation to a misunderstanding between experiments and their purpose in scientific research and practical work and its purpose in science education. He suggests that teachers, educators, and curriculum innovators overlook the fact that students do not practice science. They learn about science and also learn to practice science in laboratory settings that provide first-hand experiences.

The conditions presented above are those that research studies in science education point to as being fundamental in learning school science. How prevalent they are in classrooms where researchers have never stepped is a question to which a precise answer can not be given. It may be possible to get a sense of the situation by looking at the results of teacher research and the results of classroom studies focused upon learning where science is one part of an integrated unit, project, theme, or inquiry, and where the researcher is not a specialist in science or science education. Such rich descriptions of young children learning in formal settings exist (see Primary Voices K-6, a publication of the National Council of Teachers of English; Brass and her associates, 1994a, 1994b, 1994c; Clifford and Friesen, 1993; Cresswell, 1997; de Boo, 1999; Frost, 1997; Hall, 1998; Pearce, 1999; among others), but few are written with the details that are necessary for the analysis conceived. Nonetheless, as will be discussed, studies of this kind help to elucidate Kirschner's (1992) notion of learning about science and learning to practice science if for no reason other than the approaches utilized and described.

CHILDREN'S LEARNING THROUGH SCIENCE (FROM THE PERSPECTIVE OF LANGUAGE AND READING EDUCATORS)

Those directly and indirectly engaged in the science education of young children will have noticed the growing interest in school science, and school mathematics, that has recently been shown by educators with language and reading expertise. Many of these academics and teacher-researchers have found their way into science through the whole language movement. This is a movement described by Goodman (1989) as "grassroots" (p.115) and "embedded in the traditions of science and humanism" (p. 125). That is, it has taken the results of studies "concerning how students learn, how they learn language, how they use language to learn, and the influence of the individual, peers, teachers, and various cultural institutions on language learning and on using language to learn" from psychology, linguistics, psycholinguistics, and sociolinguistics. From humanism, it has taken "respect for, and positive attitudes toward, all learners regardless of their ages, abilities, or backgrounds" (p. 125).

As a conception engendering a popular movement, whole language has been identified as "a philosophical stance" (Newman, 1985, p. 1), "a political phenomenon" (Pearson, 1989, p. 232), and "a theory of voice that operates on the premise that all students must be heard" (Harste, 1989, p. 245). It has an interesting evolution, the retelling of which is outside the scope of this study. For present purposes, it is sufficient to say that whole language began in the mid-1960s with Ken Goodman's realization that readers make predictions and self-correct based upon their intuitive sense of syntax and whether or not what is read sounds like language that is heard (Harste and Short, 1996). Eight years later, Michael Halliday published his findings on the natural development of oral language in settings that enabled language learning through use. His research suggested to language educators and classroom teachers that "if you want a child to sound like a lawyer, have her associate with lawyers. ... if children were to be poets they needed to be immersed in poetry" (Short and Harste with Burke, 1996, p. 10).

The consequences of these and later studies on reading, writing, speaking, and listening were twofold. First, basal reading, grammar, phonetic, and writing programs that decomposed literacy acts into simpler component subskills were repudiated and cast aside. It was believed that language acts should not be simplified for instructional purposes. Thus, the second aftereffect: language instruction that encouraged learners to write and read for functional and authentic reasons (to communicate and to interpret) from the first days of formal schooling. Rather than marking vowels and correcting spelling and grammar on worksheets, children were to use written and oral language "to get something done" (Newman, 1985, p. 152): to write genuine, not simulated, letters to pen pals, invitations to guests, notes for a message board, reflections in their personal journals, and the like (Pearson, 1989; Short *et al.*, 1996). Rather than reading to practice reading or to learn reading skills, children were to use reading "to pursue their personal questions and interests, to explore class themes and topics, and to think about language" (Short *et al.*, 1996, p. 42). The goal was "to eliminate the gap between school literacy tasks and real-world literacy tasks" (Pearson, 1989, p. 234): to make communication work. The result was an awareness of the interdependence of all aspects of language, a preservation of the integrity of literacy events (Pearson, 1989, p. 234), and use of "real language experiences" in which children learned about reading and writing while listening, learned about writing from reading and about reading from writing, and learned language and about language in the context of learning about the world (Newman, 1985, pp. 5 and 152)

The practitioners and advocates of whole language have distinct views of the learner, of the teacher, of the curriculum, of knowledge, and of inquiry. These perspectives, as articulated by Copenhaver (1993), Gallas (1994; 1995), Harste (1993), Leland and Harste (1994), Short and Burke(1991), Short and Harste with Burke (1996), and Whitin and Whitin (1996; 1997), will be presented here and discussed with respect to the aforementioned conditions that science educators associate with meaningful learning.

Pearson writes that "[w]hole language advocates accept, at a minimum, a constructivist view of knowledge" (1989, p. 234). The active nature of learning is unmistakable in the following excerpt from Short and Harste with Burke concerning reading comprehension:

> Reading was no longer viewed as the transfer of the text into the reader's head, but as a process where readers actively interact with a text using their background experiences to comprehend the text.
> While a text has particular potential meanings... [r]eaders construct their understanding in light of their experiences and rethink their experiences in light of the text so that they bring meaning to and take meaning from a text. Both the reader and the text are thus changed in the transaction (1996, pp. 41-42).

The active construction of viable knowledge is generally believed to be a consequence of transactions between individuals, or purposeful interpersonal interaction. This can be seen in Burke's perception of learning as "social inquiry" (Copenhaver, 1993, p. 7) and the designation of classrooms of teachers and children as collaborative, communities of inquirers (Short and Harste with Burke, 1996; Whitin and Whitin, 1997) and dynamic learning communities (Gallas, 1994). The sociocultural nature of learning, to which these authors prescribe, is made obvious in the following passage from Harste (1993): "Knowledge only gives the illusion of residing in books, people, and disciplines. In reality, knowledge is a relationship that resides between and among people in particular times and contexts" (p. 4). It is this relationship that Short and Burke (1991) claim enables one to understand and develop personal thinking by putting into words what is known and considering what others have to say.

At first reading, the theory of cognition upon which whole language has based its "learning through meaningful use" closely resembles Condition 1 above (the development of scientific understanding is a process of personal knowledge construction that is mediated by one's social and cultural milieu). It is not always the case, however, that the personal and social process of enculturation in school science involves the discourse practices of the scientific community. Short and Harste with Burke (1996) suggest that this is the natural consequence of the adaptive function of cognition. They write, "...mentally active learners consciously pick and choose what it is that they will attend to out of what is shown to them" (pp. 12-13). As a result, not every learner will learn the same thing. It is for this reason that they prefer demonstration, conceived as an opportunity to see what can be done, over modeling which they argue engenders unthinking imitation by showing what must be done.

Gallas (1994) contends that the language of science, "using previously established vocabulary and specific cognitive structures," is an elitist discourse (p. 97). She suggests that the children in her classes will be excluded from scientific conversations and the world of science because they can't say what they know in the very precise language of science. Rather than "teach the correct usage and application of scientific concepts and terminology", she sees her role as "one of exploring children's meanings and learning to speak their dialects" (p. 98).

Whitin and Whitin (1997), like Gallas, believe that teachers have a key role to play in the development of children's language and identity. They encourage what they believe to be the language and methodological approaches of the community of scientists, and helped the children in their study "to realize that even facts and theories are only tentative best guesses" (p. 31), that stories, which blur the line between fact and fiction, are "clear and honest explanations for describing our world" (p. 43), that "knowledge changes" (p. 48), that "[l]iving with multiple theories is a natural part of scientific life" (p. 51), and that reliance on one theory "causes premature focus... and needlessly converges thoughts and ideas" (p. 53).

As will be shown, these views make Condition 3 (The development of scientific understanding occurs at the level of concept acquisition, the construction of new knowledge, and the evaluation and modification of existing knowledge.) more untenable for whole language theorists than Condition 1. There is no debate, however, with Condition 2 (The development of scientific understanding is dependent, to a great extent, on what the learner already knows.), only with what one does with this awareness.

Like the science educators above, Harste (1993) maintains that "[w]hat learners currently know... is the only starting point from which they can learn" (p. 4). This is the perspective reiterated by Short and Burke (1991) who write, "[w]hat students know is the touchstone upon which curriculum will be negotiated" (pp. 25-26). It is not the role of the classroom teacher, however, to guide children toward an understanding of the natural world that more closely approximates what is currently known by the scientific community. Whitin and Whitin, in fact, describe stepping aside when it came to finding patterns in data because they "knew children's sense-making abilities would support them in finding appropriate solutions" (1996, p. 122). Gallas writes about her decision to focus on issues of language and culture and how to bridge the gap between teacher intentions and the children's life experiences rather than intervening when children would volunteer "disturbing misconceptions" (1995, p. 11).

Teachers use idea webs, mind maps, KWL (What I know. What I would like to know. What I learned.), brainstorming sessions, and science talks, to determine the connections children may have with a topic and use these relationships in planning the invitations that will launch an emergent curriculum. As Short and Harste with Burke make clear, "[t]he goal of school is not so much to get children to out grow their commonsense ways-of-knowing as it is to legitimize and make real connections with these literacies" (1996, p. 54).

This is a consequence, Pearson (1989) suggests, of the epistemological perspective underlying whole language. Meaning no longer resides in text, thus, all comprehension is a form of interpretation. Since all readers must construct meaning, each interpretation is as valid as any other and needs only to be understood, not corrected. Communication (negotiation) is made possible as a consequence of shared, but idiosyncratic interpretations. "Knowledge", accordingly, "is only as good and stable" as the last time it was used (pp.234-235), and learners "have to accept that there are no final solutions, only current best solutions" (Short and Burke, 1991, p. 27).

Gallas (1995), in contrast to Harste, Burke, and Short, speaks of seminal questions, soliciting the child's deeply held beliefs, and using them to construct teaching and restructure "misconceptions" (pp. 56-57). If this is not done, she suggests that teacher's best intentions could "limit, rather than expand, the children's theoretical frameworks" (p. 61). Forty-one pages later, however, she castigates mandated curriculum units that give little thought to children's questions, development, potential as thinkers, out-of-school experiences, and writes:

> If we explore the kinds of thinking elementary children are capable of, we cannot help but wish the same capacity ourselves. When we are able to resurrect our own wonder and our natural imaginative response to the world, we can better teach our children, understanding as we do that "final form science" is not where science begins, but rather is an outcome that has wrongly been inserted into the education of our children (p. 102).

For the educators and teacher-researchers quoted here, "inquiry... organizes what is open to be learned" (Harste, 1993, p.3). Teaching is not guided by a manifest curriculum, and school, like knowledge, is not conceptualized in terms of academic disciplines or school subjects. Textbooks, course syllabi, and curriculum documents from which teachers are mandated to teach are perceived as "curricular constraints" (Copenhaver, 1993, p. 6), impositions (Short *et al*., 1996, p. 26), and "outside" and "coercive" forces (Short and Burke, 1991, p. 20). They not only "fix what could be learned" (Harste, p.3) but are "loaded with someone else's voice asking all the questions and demanding all of the answers" (Copenhaver, p. 6).

The general consensus is that curricula that are, in truth, learning-centered are based on personal questions that matter to the learner. In which case, the function of curricula is to support the process of collaborative inquiry and all that this entails -- "making meaning, sharing meaning, extending meaning, evaluating meaning, savoring meaning, and generating new meaning" (Harste, 1993, p. 2). This requires a shift from construing curriculum as fact with predetermined outcomes to understanding curriculum as lived (active), inchoate, and open-ended. Students become curricular informants who help to "forge the best lessons" (Whitin and Whitin, 1997, p.28) and decision makers with "real choices in the kinds of learning experiences in which they will engage" (Short and Burke, 1991, p. 5) The teacher becomes one more inquirer among many in a classroom learning community, a facilitator-helper who does "not step in front of the struggle" (Burke as quoted in Whitin and Whitin, p. 10) , and "a kid-watcher" (Goodman, 1978) who "leads from behind" by indirectly supporting the learning capabilities of students through invitations to explore (see Chaille and Britain, 1991).

Given this perspective, there is, as Gallas points out, a crucial distinction to be made "between a science environment that incorporates child-centered, hands-on methodology, but considers primarily the teacher's questions, and a classroom in which knowledge about science and the world is carefully *co*-constructed, incorporating a child-centered, hands-on methodology that is framed by children's questions" (1995, p. 9). She claims that any notion that the children are working with their own ideas in the first example is illusionary: "...the teacher is in charge of what it said... The children's remarks are filtered through the teacher's mouth... If there is discussion, the teacher orchestrates it, choosing who talks, what is said, and the most important ideas to be considered and pursued" (pp. 10-11).

Short and Burke (1991, p. 59) would agree. They state that the purpose of inquiry in classrooms of this kind is to confirm what is already known and to make that information conventional. In classrooms where an inquiry-based curriculum has been adopted, the knowledge systems, of which science is but one, and the sign systems (*e.g.* art, music, dance, mathematics and language) become the "tools for exploring, finding, and researching student questions" (Short *et al.*, 1996, p. 261). One doesn't "inquire to eliminate alternatives but to find more functional understandings" (p. 260). As a consequence, progress in school science has little if anything to do with advancement toward an understanding of scientific explanations or the development of conceptual models that are more representative of real world phenomena or entities than when the inquiry was undertaken. Progress is measured by having new understandings and new questions to ask (Short and Burke, p. 59).

As far as an awareness of the epistemological aspects of science and how scientists come to know is concerned, Whitin and Whitin are the authors represented here who address this condition, albeit indirectly. Gallas, who writes about her experiences as a teacher of science, is not interested in the presentation of final form science. She focuses instead on the scientist's early fascination with the world of nature and Gerald Holton's "thematics" – private theoretical pictures of how the world works that often emerge well before an individual becomes a scientist. Both suggest that "a love of science and the attraction to particular kinds of problems are potentially set in motion in early childhood" (1995, pp. 14-15). It is this intuition, imagination and wonder that she hopes to nurture and build upon through science talks and the metaphoric thinking and storytelling processes that children instinctively utilize to conceptualize the world (1995, p. 16; 1994, p.110).

Phyllis and David Whitin believe "[t]hat classrooms ought to be embryos of the larger scientific community" (1997, p. 60), and that children in these classrooms ought to be doing what the members of the scientific community do. This includes "sharing personal knowledge and experiences and viewing phenomena from interdisciplinary perspectives" (p. 60), using metaphor to convey observations (p. 4), solving problems collaboratively (p. 7), developing strategies to address methodological problems (p. 8), using tools (p. 11), observing closely, speculating about what is seen, and generating "theories" to explain observational data (p. 13), consulting resources (p. 33), and honing, refining, and questioning language (p. 67).

Every child in the study was considered to be a legitimate scientist, "full fledged members of the scientific community" by reason of a sense of wonder and inquiring mind

(Whitin and Whitin, 1996, p. 131). They had, however, been asked to "record a question as well as a theory" for the bird behaviours observed (p. 11). The multiple theories generated were opinions and tentative best guesses used to interpret a limited number of observations. This led to a cycle of observing, sharing descriptions, and the collaborative generation of "new wonders" and "new theories". All of the children were encouraged to challenge the group's current understandings, for according to their teachers, "[t]he history of scientific thought is nothing but a trail of revolutionary challenges to the established assumptions of the day" (p. 94). The anomalies were what kept the children returning to the window, "watching to confirm, revise, or abandon the theories" that had been proposed (p. 127).

What can be interpreted as indifference to the many issues of importance to science educators is in part attributable to the ideological position that underpins the whole language/whole literacy movement. The position and concomitant beliefs about what should be taught, for what reasons, and for what ends include those that are central to progressive educational ideology. Eisner's description, given below, of John Dewey's ideas for American education could just as easily have been written with whole language in mind:

> No longer was it appropriate to regard the child as a passive receptacle to be filled with curriculum content. No longer could mind and emotion be regarded as independent. No longer could the curriculum be regarded as a static, fixed body of content, created in administrative offices and handed down to teachers. The child acted on the environment, not simply digested it, and in the process that environment was personally transformed. Emotion could not be disregarded in dealing with intellectual matters since how children felt about what they studied influenced how they thought about what they studied. As for the curriculum, it could not be optimally developed by people who had never seen the child; hence teachers needed to play a fundamental role in its creation (1992, p. 312).

Of more relevance here than ideological stance, however important, is Dewey's theory of inquiry. It is perhaps the principal explanation for the inquiry in inquiry-based curricula having little resemblance to the scientific inquiry underpinning the instruction in school science envisioned by science educators. This inconsistency raises a number of questions the answers to which have significant consequences for the science children encounter in formal schooling.

There is, of course, the notion of inquiry – how it is conceived, how these conceptualizations become translated and expressed in curriculum documents, whether emergent and in the minds of learners or made manifest in print, and why it is believed, almost as a matter of course, to be central to learning.

Whether the inquiry in which learners engage is scientific or critical reflection joined to intelligent action (whatever the degree of genuineness) there remains the reality of personal knowledge and mental models and the entrenchment and tenacity of each. One wonders, given the "naïve and incommensurable ways of seeing and thinking about the natural world" that Macbeth identifies as an obstacle to scientific understanding, to what use this information should be put. Is awareness on the part of a teacher sufficient, or must the learner's conceptions be made explicit for both the teacher and the learner (or class of learners) so that they play a dominant part in the teaching-learning process as Champagne and Bunce, and Hewson and his colleagues maintain? All efforts by science educators to find a reasonable solution to this "conundrum" take place without addressing the problem that is mentioned by Gallas and alluded to by others like Freyberg and Osborne (1985). That is, when should a child be introduced to, or guided toward, a particular scientific viewpoint or, more aptly, when does a learner benefit from a scientific perspective?

This brings to the fore the role of the teacher and the role of the learner and what it means to "take ownership" of one's learning. Is it necessary, for example, that a teacher does more than orchestrate the learning environment, observe learners engaged in that environment, and extend invitations? Does orchestrating the environment for learning entail the kind of teaching that Vygotsky envisioned when he wrote about the zone of proximal development, or that Hunt and Minstrell (1994) embed in their "benchmark instruction", or that Glynn and Duit (1995) view as essential if learners are to construct new knowledge in the form of conceptual models? While learners' questions may be an appropriate starting point for "authentic pedagogy" as has been claimed, does it necessarily follow, as Zuckerman and her colleagues (1998) allege, that information not deliberately sought is either forgotten or never incorporated into a system of ideas that is personally meaningful? Regardless of the origin of the question or problem posed, if learning is generative and assisting the learner in building and refining conceptual models, is it not also the learner's own, or is school to be a place, as Leland and Harste believe, where children follow their bliss and natural inclinations?

These are the questions this study set out to explore. As with all qualitative research, several were eliminated, others added, and a few refined as the field work got underway and it became clear that what had been planned was not necessarily going to be what would take place. The study began, nonetheless, with inquiry and its history in North American science education and then moved out of the literature and into the lives of nineteen children for that period of the weekly school cycle set aside for science. The impetus for a curriculum-based study was a passage in a 1993 review of early science education in which the following observation was made:

> It is important to note that those who come from a background in developmental or early childhood education tend to take a different approach to early science education from those who come from a background in science or elementary education. The former group focuses more on the child and the teacher, extending the methods and ideas of preschool education upward into primary school. The latter group focuses more on the processes and content of science, extending the methods and ideas of the upper grades downward into the primary grades and kindergarten. For the former any developmentally appropriate activity is acceptable and useful; for the latter there are specific ideas and activities that are thought to be a necessary part of children's education (Howe, 1993, p. 228).

When one is made aware of the dissimilarity that Howe has perceived and communicated, and the preceding pages intended to make evident, the early years literature with a science education focus can be seen to be less ambiguous and confused. There are, however, two groups of academics, writing for teachers and one another, at what can be interpreted as cross-purposes. One group focuses upon children's inquiry, curriculum as inquiry, and teaching/learning through inquiry and regularly uses natural history or field studies as the context. The other group focuses upon children's scientific inquiry and aims to reflect the nature of science as closely as it is possible with children in formal settings who are learning not only the methodologies but also the content of the discipline. Howe's clarification, being little more than this, offers no resolution or course of action by which the situation might be ameliorated. These circumstances, in my view, call for a "rapprochement" equal in significance to the one Matthews (1990) claimed to be underway between science education and the history and philosophy of science after "twenty-five years of mutually exclusive development" (Duschl, 1985). I would hope that the study before you will have as much to say to early years teachers who avidly read *Primary Voices* and works like those by Burke, Gallas, Harste, Short, and the Whitins as the curriculum enables the children for whom they are responsible to begin to see the world and their education in science in a richer and more coherent and generative way. It is my belief that if attempts by science educators are not made to build upon the inspiring work underway in early years classrooms where inquiry approaches to literacy learning have been extended into core subject areas, children will leave Grade 4 with knowledge of science that is unrecognizable to philosophers and historians and with rich, tacit knowledge in science that is distinctly different from the corresponding concepts, principles, laws, and theories held by the community of scientists.

IMPLICATIONS FOR RESEARCH

Lindfors wonders whether the prevalence of inquiry in language education journals suggests a trendy, vacuous stance or a serious trend (1999, p. 127). From the perspective of school science, Bybee, like Welch and his colleagues (1981) and Jackson (1983) earlier, suggests that it's a serious stance taken by science educators that has not changed the teaching or learning of science in classrooms. He writes: "Most evidence indicates that science teaching is not now, and never has been, in any significant way, centered in inquiry whether as content or as technique" (2000, p. 42). It would seem, as in the Sputnik and post-Sputnik era, that the enacted curriculum rarely corresponds with the curriculum envisioned by its developers. For this reason, one hesitates to design a curriculum for school science that is grounded in the initiating phase of inquiry and report upon the consequences of its utilization. Be it naiveté or an unfaltering belief that early years teachers, however sophisticated in their understanding of science, generally have the best interests of children in mind and genuinely desire sound resources that render curricular outcomes/standards accessible, this is the course upon which I chose to embark. I proceeded, driven by the conviction that theories, drawn from a variety of disciplines, exist in no small part to inform and guide teaching while at the same time being fully aware that there is no "best way of teaching something to someone" (Jackson, 1970, p. 21).

While it would be an overstatement to suggest that the design of the curriculum developed for this study has accounted for all that has been presented above, the following assumptions, models, and/or conceptions have implicitly guided the selection and sequence of activities as well as the stance the teacher is to assume with respect to the subject matter and the children and, as a consequence, that which children are ultimately enabled and encouraged to do. These are, in no particular order, Dewey's understanding of interest, Stinner's LEP Model of Concept Development, Lehrer, Carpenter, Schauble, and Putz's conception of design tools, Hodson's stages through which theories should pass during a child's school science education, and Metz's critical analysis of "developmental appropriateness" in science curricula. Each is itemized and more fully defined below.

1. Dewey's (1913) understanding of interest, and assertion that subject matter, objects, and ideas are not made interesting by being "surrounded with artificial stimuli and with fictitious inducements to attention" (p. 7).

Rather, interest is active, objective, and personal (p. 16): it functions for the individual as a genuine means of carrying on and developing a more inclusive and enduring line of activity (pp. 42-43). This can be seen to be reflected in Butzow's (1973) claim that the National Science

Foundation-funded programs of the 1960s and 1970s were developed for the child as a child, Lindfors (1999) conception of inquiry as "a language act in which one attempts to elicit another's help in going beyond his or her own present understanding" (p. ix), and Claxton's (1993b) position that to learn or not to learn depends as much upon personal goals and personal resources as it does upon situational demands and situational constraints.

2. Stinner's (1992) LEP Model of Concept Development that links the logical plane (the concepts, conceptions, and finished products of science, such as laws, principles, models, theories, and scientific facts) with the evidential plane (the experimental, intuitive, and experiential connections that support what has accumulated on the logical plane) and the psychological plane (the learner's intuitive understanding and learned science conceptions).

Like Ausubel (1963), Bruner (1963, 1966a, 1990), Glynn and Duit (1995), Novak (1993, also see Mintzes and Wandersee, 1998a), Posner, Strike, Hewson, and Gertzog (1982), Wittrock (see Osborne and Wittrock, 1983), and others, Stinner has developed a view of knowledge building that is derived from learning theory and begins with the personal knowledge and beliefs of the learner. As does Novak's "human constructivist" view and the conceptual change model of Posner and his colleagues, Stinner's model incorporates a philosophical perspective based upon epistemology derived from the history and philosophy of science. It is unique in making explicit two necessary components of science content knowledge. These are declarative knowledge (knowing that) and operative knowledge (knowing how) as defined by Arons (1983). While operative knowledge includes procedural knowledge, in this case the methodologies of science for both discovery/generating and justification/validating, it also involves an understanding of the source of the concepts, conceptions and finished products of science. This latter aspect is exemplified in questions, such as: How do we know that…? What do we mean by…? How do we recognize the…? What is the evidence that…? (Arons, 1983, p. 94). The LEP Model, when used as a guide for planning science lessons, can be seen to reflect many of the issues associated with meaningful learning in school science presented above.

3. Lehrer, Carpenter, Schauble, and Putz's (2000) conception of design tools.

These are the teacher attitudes, skills, and strategies that are believed to be necessary for the promotion of learning and the development of children's conceptual tools and conceptual models (*cf.* Bruner's (1983) scaffolding and Vygotsky's (1978) view of presenting ideas in advance of development and locating learning tasks within the zone of proximal development). They represent all that a teacher has available for making learning contexts effective. Lehrer and his colleagues discuss the design tools that support scientific inquiry in early years classrooms. These are questions, forms of argumentation and justification, children's inscriptions (*i.e.* records, drawings, mathematical formulae, measurements, and the like), the construction of models, shared experiences, and negotiation. Without the modeling and guidance of teachers, they claim that students will seldom move beyond simple assertions owing to the fact that the interplay between questions, inscriptions, and argument "does not spontaneously emerge" (p. 97). This can be seen to reflect, in varying degrees, Gaskin's (1994) notion of teachers as "learning coaches" as opposed to "knowledge tellers", Hodson's (1999) understanding of assisted performance and guided participation in school science, and the central roles that teachers, as the more expert learners, undertake in Glynn and Duit's (1995) model of constructive science learning, Hunt and Minstrell's (1994) cognitive approach to the teaching of physics, and Brown and Campione's (1994) community of learners project.

4. Hodson's stages through which theories should pass during a child's school science education.

These stages are the following:

1. Tentative introduction as one of several models.
2. A search for evidence through observation and experiment.
3. Selection of the best corroborated model by a process of criticism and discussion with others.
4. Further elaboration of the chosen model into sophisticated theory. During this stage concepts are refined and conceptual relationships are more clearly established.
5. Acceptance of the theory into the body of scientific knowledge – consensus within the class.
6. Use of the theory to explain phenomena. Application of the theory in new situations.

> 7. Testing the theory's capacity for predictions. During these later stages the theory may be made quantitative, as precise mathematical relationships are established (1990, p. 300).

The seven stages were designed to take into account the well established ideas and explanations of children, and the knowledge that conceptual frameworks are not fixed but mutable, and progressively so. Hodson (1988) recommends that teaching begin with the elicitation of children's conceptions and that these be discussed, explored, tested, applied, refined, used in making predictions, and challenged before the "official explanatory framework" is introduced and examined in an identical manner. Such a strategy and the accompanying activities can be seen to reflect Hewson and his colleagues' (1998) guidelines for teaching for conceptual change reported above as well as the SCIS learning cycle developed by Karplus (1964b), and contemporary modifications thereof (*e.g.* Barba, 1998; Beisenherz and Dontonio, 1996; Bevevino, Dengel and Adams, 1999, among others).

5. Metz's (1995, 1997, 1998) critical analysis of "developmental appropriateness" in science curricula and the assumption, drawn from Piaget's work, that the science education of young children, who are generally considered to be concrete thinkers, should be restricted to hands-on activities focused on their intellectual strengths, namely: observation, ordering, categorization, inferences and communication.

She claims that such a perspective not only underestimates children's capacities, but results in watered-down science curricula and "building-block" approaches to learning that are decontextualized, impoverished with respect to the nature of science, and uninteresting (1995). Drawing upon instructional theory and the cognitive developmental literature, Metz argues that stages of cognitive development are not "inflexible, hard-wired constraints on children's reasoning, within which the teacher must teach" (2000, p. 372). Researchers have simply confounded children's limited domain-specific knowledge with developmentally weak information processing (1997). That is to say, cognitive performance, or the adequacy of scientific reasoning capacities, is more robust in areas where children have developed extensive knowledge and become experts (*cf.* Inagaki, 1992). She insists that one "cannot infer that students are incapable of some form of inquiry without making sure that they have adequate understanding of the domain" in which the capacity is investigated (1998, p. 93). The corollary is to scaffold the knowledge that is most fundamental, and in Metz's study, this becomes that which is most fundamental to scientific inquiry, specifically: domain specific knowledge, knowledge of the nature of science, domain specific methodologies, data representation, data analysis, the fundamental constraints on statistic and probability, and relevant tools (1998). When this is attempted, it appears that children's thinking is not tied to singular, linear ideas or to the concrete, and inquiry in school science extends beyond that reflected in the developmental literature and the majority of elementary classrooms (1998 and 2000). This can be seen to reflect Hatano's (1993), Hodson's (1999), Howe's (1996), and Inagaki's (1992) calls for a Vygotskian-sociocultural conception of development in early childhood science education. Moreover, the attention Metz gives to peer tutoring, collaborative work, open exchange, and the social construction of ideas reflects the writing of Adams and Hamm (1998), Barnes (1992), Bruner (1986, 1990), Cadzen (1988), Gallas (1994, 1995), Lemke (1990), Roth (1995), Wells (1986, 1995), Wells and Chang-Wells (1992), Zuckerman, Chudinova, and Khavkin (1998), and others too numerous to mention here.

Summary and Rationale

My interests are curricular and focused upon teaching that enables children to use their minds well. The design of a science curriculum for the earliest years of formal schooling that consciously incorporates the thinking underpinning the five previous statements would seem to be all the justification one would need to suggest that a unique contribution to science education is being made. The study that was planned and carried out, however, also addressed three issues raised in the science education literature as being in need of investigation.

The first of these was made explicit by Hodson (1990) who pointed out the urgency of producing curriculum materials that would "present a more human face for science and challenge some of the myths and mistaken assumptions about science" that have been shown to pervade much of contemporary science education irrespective of the level (p. 308). With these resources in hand, he suggests focusing research on the relationship between teachers' views and the curriculum experiences provided and, what is of particular interest here, the relationships between curriculum experiences and learning outcomes.

Howe (1993), in contrast to Hodson, challenges researchers to identify those science concepts that children restructure (a) through every day experiences, (b) through appropriate guided experiences, and (c) through analogies, models, mathematical expressions, and other representations that are inaccessible and must be presented. It is her belief that "research in this area could provide a theoretical basis and a practical guide for developing science activities for young children" (p. 232).

Metz (1997) builds upon Howe's invitation with the suggestion that researchers in science education and developmental psychology need to look at "age-correlated weaknesses" in thinking (p.156). She cites a conclusion reached by the Benchmark authors and substantiates their view that too many studies have focused upon the limitations attributed to developmental stage rather than what students at this level "might possibly learn if instruction were more effective" (AAAS, 1993, p. 11). Her request is for a research base that distinguishes (a) weaknesses that are robust at a particular stage but readily ameliorated at a subsequent stage, (b) weaknesses that respond in varying degrees to instruction, and (c) weaknesses that constitute an enduring challenge irrespective of age and level of expertise (Metz, 1997, p. 156).

[1] See Anderson, 2000; Bemowski 1991; Collins, 1997 and 1998; Fensham 1988; Fort, 1993; Gardner, 1983; Grobman 1989; Hurd, 1997; Matthews, 1994; Raizen, 1991; Shamos 1995; Wallace and Louden 1998; among others.

[2] See American Association for the Advancement of Science, 1993; Council of Ministers of Education, Canada, 1997; Duschl, 1990; Fensham, 1985 and 1992; Hurd 1997; Manitoba Education and Training, 1999; National Research Council, 1996; Rutherford and Ahlgren, 1989; Spillane and Callahan, 2000; van den Akker, 1998; Wallace and Louden, 1998; among others.

[3] Knowledge construction and reconstruction; weak restructuring and radical restructuring; novice and expert problem solving performances; strategic, metastrategic and metacognitive competenceis; self-regulated comprehension; knowledge-based mediation; dyadic/proleptic instruction; anchored instruction; situated cognition; cognitive apprenticeship; contextual learning; distributed intelligence; conditionalized knowledge; discourse-oriented teaching; the narrative/social construction of reality; canonical and sociocultural reform; zone of proximal development; interactional scaffolding; philosophically valid science curricula; authentic science activity; humanistic science education; scientific inquiry; scientific community; community of inquiry; enculturation into scientific practices; revolutionary/conceptual change; antimethodism; and the like.

[4] Meaningfulness is an ambiguous term. Cognitive and constructivist theories of learning put forward by Jean Piaget, David Ausubel, M.C. Wittrock, Ernst von Glaserfeld, and Jerome Bruner hold that learner's construct their own meanings for the knowledge they acquire. From this perspective, meaningfulness differs little from understanding. Smith (1990), in fact, uses the terms synonymously (see p. 36). A concept, for example, becomes meaningful as it is understood and the link or links to some prior knowledge is/are made. Harlen (1992), on the other hand, argues: "Ideas that are learned with understanding are identified as those which make sense to the learner". Meaningfulness, whatever it may entail, appears to be built into the construction of conceptual models that organize one's ideas and their interrelations (Glynn *et al.*, 1991; Mintzes and Wandersee, 1998a). Owing to the wide variety of relationships that can exist between new phenomena and existing knowledge, meaningfulness is idiosyncratic and multidimensional. It is this sense of meaningfulness that pervades the literature of education. It is the essence of Bruner's (1963) spiral curriculum, the gist of Posner, Strike, Hewson, and Gertzog's (1982) condition of intelligibility for conceptual change, and one of the prerequisites that Smith (1975) argues must be met before a student can learn. He writes: "[T]here must be a point of contact between what the student is expected to know and what he knows already". This point of contact, however, need not be practically relevant or tied to everyday experience. As Floden, Buchmann, and Schwille (1987) note: "In working with methods and content different from everyday experience [for example, theoretical objects and entities that are not observable without the aid of instruments], students may begin with only a faint idea of what it all means, but that faint glimmer of understanding may be enough to make instruction meaningful". There are a growing number of teachers and teacher educators, however, whose calls for meaningful learning and meaningful instruction are not based upon this particular sense of the term. They argue for continuity between what one learns in school and what one needs to know outside of school (an end to the "encapsulation of school learning") and for opportunities that enable each learner "to connect" his or her everyday life with school life (see Berghoff and Egawa, 1991; Brown et al., 1989a; Cassidy and Lancaster, 1993; Chapman, 1992; Clifford and Friesen, 1993; Engestrom, 1991; Fleer, 1992; Holt, 1989; Hurd, 1991; Klein, 1991; Mechling and Oliver, 1983; O'Loughlin, 1992; among others).

[5] By definition, understanding is comprehension - to perceive and comprehend the nature and significance of the events in which one is involved. According to Smith (1990), understanding is the opposite of confusion. It represents an activity, like breathing, that is natural and continuous, but in which one must be actively engaged. That is, one brings understanding to a new situation rather than waiting, passively, for the situation to make sense. As such, Smith argues, "(u)nderstanding is thinking". He writes:

> The brain is not doing different things when we understand and when we think...I do not understand something and then think about it - I cannot understand it without thinking about it. And I cannot think about something and then understand it. My

> understanding may change in the course of my thinking, but there must be original understanding that is modified as my thinking continues. Thinking proceeds from understanding to understanding. Understanding, in other words, is simply the present tense of thinking.

To understand a fact, concept, communication, situation, person, or entire domain it necessarily follows that a repertoire, or number of elements, of knowledge must be present in one's "long-term" memory. These elements can include propositions (facts, opinions, or beliefs), strings (proverbs, mnemonics, multiplication tables, and the like), images (mental representations of sensory perceptions), episodes (memories of events), intellectual skills (capacities to carry out classes of tasks), motor skills (capacities to perform classes of tasks), and cognitive strategies (broad skills used in thinking) (White, 1988). White and Gunstone (1992) contend, that "[t]he richer this set [of elements], the better its separate elements are linked with each other, and the clearer each element is formulated...the greater the understanding". Given these descriptions, it is a misrepresentation to suggest that one either understands or does not understand. Understanding is a continuum, not a dichotomous state - "(e)veryone understands to some degree anything they know something about" (White and Gunstone, 1992). Learning that is concerned with understanding, as a consequence, is not an all or nothing affair (*i.e.* correct, incorrect; right, wrong). As Wells and Chang-Wells (1992) state, "it involves the cumulative construction of knowledge over many encounters with relevant problems, with the learner bringing what was learned on previous occasions to make connections with the information presented in each new problem and thereby making more and better sense of the phenomena in question". In this regard, Snow and Lohman (1989 as cited in Harnish and Mabry, 1993) suggest, that "a significant part of the learner's task is continually to assemble, reassemble, structure and fine-tune the accumulating body of knowledge into functional systems for use in thought and in further learning". Understanding, as a consequence, is never complete (White and Gunstone, 1992).

[6] Concordant with Glynn and Duit (1995), the distinction between mental models and conceptual models as described by Norman is utilized. Mental models are personal, private, generally implicit, everyday representational constructions of the real world (*cf.* Gilbert and Boutler, 1998). Conceptual models are scientifically valid representations of a real world process, event, phenomenon, organism, object, or material (*cf.* Gilbert and Boutler's "teaching models" that are used to aid the learner's understanding of "consensus models" drawn from the scientific community). They are formally presented, and evolve as the child's sophistication with natural phenomena grows and develops.

[7] Roberts (1982, p. 245) defines curriculum emphasis in science education as "a coherent set of messages to the student *about* science". These messages, whether explicitly stated or implicit, have little to do with subject matter but provide answers to the question, "Why am I learning this?" Seven emphases are identified and designated with the following labels: everyday coping; structure of science; science, technology and decisions; scientific skill development; correct explanations; self as explainer; and solid foundation.

[8] Beginning in 1989 with the Brown, Collins, and Duguid article on situated cognition, followed by responses from Palinscar (1989) and Wineburg (1989) and Brown, Collins, and Duguid's (1989b) rejoinder, Educational Research has run a series of articles on cognitive and situated learning, the most recent being Cobb and Bowers' (1999) synthesis of an exchange between Anderson, Reder, and Simon (1996 and 1997) and Greeno (1997), and the critical look by Sfard (1998) at the "acquisition metaphor" of constructivism and the "participation metaphor" of sociocultural approaches in educational research. These papers present a number of provocative ideas that are beyond the scope of this proposal. The astute reader will, nonetheless, find bits and pieces permeating the introduction in a manner that obscures the fundamental argument as stated by Cobb (1994), "Where is the mind?" Cold-blooded theorists locate knowledge, an entity and commodity, solely within the individual. Hot-blooded theorists do not talk about knowledge or concepts or transfer but speak of practice, context, situation, discourse, and communication. For these theorists, knowing is "an activity that is situated with regard to an individual's position in the world of social affairs" (Cobb and Bowers, 1999). The perspective taken here more closely resembles the position of Hewson, Beeth and Thorley (1998, p. 202) and Driver and Scott (1995, p. 28) that embraces both positions.

CHAPTER THREE

INQUIRY IN SCIENCE TEACHING AND LEARNING

The term enquiry is sometimes used to mean "the scientific method" – that is, it may be a synonym for "invention," "construction," "discovery," "verification," and "research." And then it may be used quite differently to mean "thinking," "divergent thinking," or "problem solving." Yet again it may refer to a method of teaching, as, for example, by those who talk of "discovery" teaching" (Connelly, Finegold, Clipsham, and Wahlstrom, 1977, p. 3).

Before looking at the current reform efforts in North American science education, it's worthwhile, even profitable, to become reacquainted with the instructional materials developed in the early 1960s under the auspices of the National Science Foundation. The following section begins by looking at four men, John Dewey, Joseph Schwab, Jerome Bruner, and F. James Rutherford, who were pivotal in defining what was and continues to be meant by inquiry. It continues with an examination of the three leading programs that were designed specifically for young children, namely: Science: A Process Approach, Science Curriculum Improvement Study, and Elementary Science Study. Following a discussion of the similarities and differences between these curriculum projects, the reasons given for their nonsuccess are presented.

JOHN DEWEY

Dewey may have been the first American philosopher of education to write a monograph on inquiry, *Logic: The Theory of Inquiry*, yet his name is seldom mentioned in the literature of the science curriculum development projects of the 1960s. He has, however, had an appreciable impact on curriculum construction in, and social organization of, the early years classroom and for this reason is included here.

Dewey drew upon the collected papers of C.S. Peirce in formulating his theory of inquiry (Fisch 1986, as cited in Siegel and Carey, 1989, p. 21). Peirce defined knowledge as a process of settling doubt and fixing belief through deliberate and self-controlled thought. The process began with an anomaly, uncertainty, or judicious skepticism and, through the processes of abduction, deduction and induction,[1] ended in meaning, not enduring truth. Dewey, through Peirce's writing, came to see inquiry as a joining of reflective thinking and intelligent action in the world (Siegel and Carey, 1989).

Dewey defines reflective thinking as "[a]ctive, persistent, and careful consideration of any belief or supposed form of knowledge in light of the grounds that support it and the further conclusions to which it tends" (1933, p. 9). Unlike other thought processes, Dewey believes that reflective thinking is "the kind of thinking that consists in turning a subject over in the mind and giving it serious and consecutive consideration" (p. 3). Reflection differs from daydreaming and the "random coursing of things through the mind" since each idea grows out of the one that precedes it and determines the one that will succeed it – "reflective thought is a chain" (p. 4). Reflection differs from imaginative flights of fancy by having a purpose or goal, beyond entertainment, that guides and controls the sequence of ideas – "reflective thinking aims at a conclusion" (pp. 5-6). And, reflection differs from beliefs and prejudices that rest upon custom or authority because the answer or solution is a consequence of personal examination, scrutiny, and conclusions based on evidence – "reflective thinking impels to inquiry" (pp. 6-7).

Dewey claims that one complete act of critical reflection, also called a unit of thinking, begins with a pre-reflective situation represented by a state of doubt, confusion, or perplexity and ends in a post-reflective situation where doubt has been dispelled, confusion has been resolved, or the perplexity has been disposed (1933, pp. 106-107). Between pre-reflective and post-reflective conditions, Dewey identifies the following five, non-sequential functions of thought: (1) Suggestion – direct action is delayed as the mind begins to rehearse possible solutions to the difficulty/perplexity; (2) Intellectualization – the difficulty/perplexity causing inaction is no longer considered an annoyance (an emotional quality), but becomes a true problem to be defined and solved (something intellectual); (3) The Guiding Idea, Hypothesis – the first suggestion for solving the difficulty pops into mind and is followed by others that become working hypotheses by which one is led to make more observations, to collect more factual material, and to refine the explanatory idea until it is more adequate; (4) Reasoning – prior experience and education are used to elaborate and transform ideas and inferences; and (5) Testing the Hypothesis by Overt Action – the theoretical, or rationally deduced conclusions, are tested against direct observations or experimental results (pp. 107-115).

Dewey (1933) argues for reflective thinking, the power of thought that enables "genuine freedom," as an educational aim. He urges that training in the above listed aspects of thought and the cultivation of attitudes that predispose one to employ methods of critical reflection and inquiry (open-mindedness, whole-heartedness or absorbed interest, and responsibility in facing consequences) begin in childhood. He does not believe that reflective thinking is "a special, isolated natural tendency that will bloom inevitably in due season," but understands that mental habits are shaped and refined alongside occasions for thinking in early childhood. It is, therefore, the educator's responsibility and obligation, as the following excerpt makes clear, to ensure that the mental habits formed are those that enable actions to be guided by the thoughtful conclusions of inquiry as opposed to impulse, appetite, caprice, or circumstances of the moment. He writes,

> In any case positive habits are being formed: if not habits of careful looking into things, then habits of hasty, heedless, impatient glancing over the surface; if not habits of consecutively following up the suggestions that occur, then habits of haphazard, grasshopper-like guessing; if not habits of suspending judgment till inferences have been tested by the examination of evidence, then habits of credulity alternating with flippant incredulity, belief or unbelief being based, in either case, upon whim, emotion, or accidental circumstances. The only way to achieve traits of carefulness, thoroughness, and continuity is by exercising these traits from the beginning, and by seeing to it that conditions call for their exercise (1933, p. 89).

The pedagogical question, from this perspective, becomes one of orchestrating learning and the learning environment so that these habits and traits are practiced. Because Dewey is convinced that the process of thinking, when carried on reflectively, is logical, he criticizes those who presume that the mind is illogical and can "become logical only through absorption of logically formulated, ready-made materials" (1933, p. 79). He is equally critical of those who assume that the young mind is so naturally adverse to logical form that logical order is out of place in an education focused upon free self-expression, spontaneity and natural unfolding (p. 83). In the first instance, the logical is identified with formal properties of the subject matter and the conclusions of an expert, trained mind. In the latter, expression in the activities of the child is not seen as being intellectual. Dewey offers the following counsel:

> Some kind of intellectual organization must be required, or else habits of vagueness, disorder, and incoherent 'thinking' will be formed. But the organization need not be that which would satisfy the mature expert. For the immature mind is still in the process of gaining the intellectual skill that the latter has already achieved. It is absurd to suppose that the beginner can begin where the adept stops. But the beginner should be trained to demand from himself careful examination, consecutiveness, and some sort of summary and formulation of *his* conclusions, together with a statement of the reasons for them(1933, pp. 84-85).

Accordingly, Dewey came to equate learning with learning to think (1933, pp.78-79), and thinking with the scientific method of knowing (1910, p. 127) "as he saw it" (Atkin 1968, p. 6). In a 1909 address to the American Association for the Advancement of Science, he submits that the knowledge of most worth, if one can classify knowledge in the manner of Herbert Spencer, is "knowledge of the method of knowing" (Dewey, 1910, p. 125). With respect to science education, this is "the construction of a scientific habit of mind" as opposed to familiarity with the facts of nature, universal principles and laws. He writes, "[s]ystematized knowledge is science only because of the care and thoroughness with which it has been sought for, selected and arranged," and proposes that "in the order both of time and importance, science as method precedes science as subject-matter" (1910, p. 125).

Dewey recommends that a reflective and critical attitude toward the study of science be fixed during the earlier years of life (1910, p. 123), but he advises that "an habitual disposition of mind" that transfers "guess and opinion into belief authorized by inquiry" will not occur with the acquisition of laboratory methods (p. 125). Laboratory exercises and the technical methods employed in school science are more often than not "liturgical" and have little to do with scientific method as "conscious instrumentalities" for making knowledge (1910, p. 125). He writes,

> Scientific method is not just a method which it has been found profitable to pursue in this or that abstruse subject for purely technical reasons. It represents the only method of thinking that has proved fruitful in any subject – that is what we mean when we call it scientific. It is not a particular development of thinking for highly specialized ends; it *is* thinking so far as thought has become conscious of its proper ends and of the equipment indispensable for success in their pursuit (1910, p. 127).

Dewey believes that science teaching has fallen short of the claims made for it, not only in failing to attract students but also in not aiming to develop within the American populace a scientific habit of mind. It is the later omission, he suggests, that has contributed to flippancy of belief, quasi-skepticism and the detriment of natural common sense, and he has no doubt that the future of civilization depends upon the reparation of this condition (1910, pp. 126-127). For this reason, he recommends that literary education be gradually replaced by a scientific education, that educators determine "how to mature and make effective" the scientific habit of mind, and that schools "become laboratories of knowledge-making, not mills fitted out with information-hoppers" (p. 127).

JEROME BRUNER

In September 1959, almost two years after the Soviet satellite Sputnik began its orbit of Earth, the Education Committee of the National Academy of Science in the United States called together thirty-five scientists, mathematicians, historians, psychologists, and educators to appraise the new science and mathematics curricula being created for primary and secondary school students. The chairman of the ten-day gathering, what is now referred to as the Woods Hole Conference, was Jerome Bruner. In 1960, Bruner's report of the major emphases and issues of the five working groups of the conference was published with the title, *The Process of Education*. In the text of this report are thoughtful concerns and perceptions, such as the structure of a discipline,[2] spiral curriculum,[3] readiness for learning,[4] and, of particular interest here, inquiry/discovery, that were to reverberate through the education literature for the next two decades.

Amongst science educators, *The Process of Education* is commonly acknowledged as the document that roused interest in inquiry/discovery approaches to learning, though Shulman (1968, p. 35) submits that mathematics innovations using discovery as a core had already begun when *The Process of Education* was written. Bruner's ideas with respect to inquiry/discovery learning are rudimentary or, at the very least, underdeveloped in this presentation. He writes:

> Mastery of the fundamental ideas of a field involves not only the grasping of general principles, but also the development of an attitude toward learning and inquiry, toward guessing and hunches, toward the possibility of solving problems on one's own. Just as a physicist has certain attitudes about the ultimate orderliness of nature and a conviction that order can be discovered, so a young physics student needs some working version of these attitudes if he is to organize his learning in such a way as to make what he learns usable and meaningful in his thinking. To instill such attitudes by teaching requires something more than the mere presentation of fundamental ideas. Just what it takes to bring off such teaching is something on which a great deal of research is needed, but it would seem that an important ingredient is a sense of excitement about discovery – discovery of regularities of previously unrecognized relations and similarities between ideas, with a resulting sense of self confidence in one's abilities. Various people who have worked on curricula in science and mathematics have urged that it is possible to present the fundamental structure of a discipline in such a way as to preserve some of the exciting sequences that lead a student to discover for himself (1963, p. 20).

In the paragraph that succeeds this excerpt, Bruner poses two questions, "Is the inductive approach a better technique for teaching principles? Does it have a desirable effect on attitudes?" These are addressed the following year in his paper, *The Act of Discovery.* Using Maimonides' *Guide for the Perplexed*, Bruner (1961, p. 22) suggests that the most uniquely personal of all that one knows is that which one has discovered for oneself. This idea, in combination with the knowledge accumulating in psychology[5] that children, left to themselves, will discover, led Bruner to hypothesize that a classroom environment and style of teaching that encourages and predisposes children to want to discover, and thereby learn through the discoveries they make, will result in four, very positive effects. These are: increase in intellectual potency; the shift from extrinsic to intrinsic motives/rewards; learning the heuristics of discovery; and the conservation of memory.

By intellectual potency, Bruner is referring to the acquisition and processing/organization of information that enables future retrieval and use. He suggests that learning through discovery teaches the child an approach to information gathering "that makes that information more readily viable." It is focused, so as to give shape to hypotheses, and it is connected and organized, so as to discover regularities and relatedness while avoiding cognitive overload and information drift. He writes, "I would urge now in the spirit of an hypothesis that emphasis on discovery learning has precisely the effect upon the learner of leading him to be a constructionist..." (1961, pp. 23-26).

Bruner submits that the child, who learns in response to rewards and punishments, does not have the capacity to transform his/her learning into viable thought structures that relate to the rest of his/her cognitive life. If, however, the child is able to approach learning as discovery, s/he will come to experience success and failure as information that s/he is on the right or wrong track, not as reward and punishment, and the applicability/correctness of new ideas can be checked immediately against experience rather than from cues given by the teacher. He writes, "...I am proposing that the degree to which competence or mastery motives come to control behavior, to that degree the role of reinforcement or 'extrinsic pleasure' wanes in shaping behavior (1961, pp. 26-29).

By heuristics of discovery, Bruner does not mean the formal aspects of inquiry (logic, statistics and mathematics). He is referring to strategies of attack, or a series of activities and attitudes, some specific, some general, that permeate inquiry and research and "have to do with the process of trying to find out something" (1961, p. 30). One example, discussed by Bruner, is the invention, development, and imposition of a puzzle form on to a difficulty that has the potential to recast the difficulty as a problem that can be worked with and solved. His hunch is that children learn the working heuristic of discovery "only through the exercise of problem solving and the effort of discovery" (p. 31). He writes, "[p]ractice in inquiry, in trying to figure out something for oneself is indeed what is needed, but in what form? Of only one thing I am convinced. I have never seen anybody improve in the art and technique of inquiry by any means other than engaging in inquiry" (p. 31).

With respect to memory and the retrieval of information (conservation of memory), Bruner proposes that the problem is one of knowing how to place information in memory so that it can be recalled on demand. He suggests that the material that has the best chance of being retrieved is "material that that is organized in terms of a person's own interests and cognitive structures" and that has been "placed along routes that are connected to one's own ways of intellectual travel" (1961, p. 32). As regards discovery learning, he writes, "the very attitudes and activities that characterize 'figuring out' or 'discovering' things for oneself also seem to have the effect of making material more readily accessible in memory" (p. 32).

Returning to the two questions posed by Bruner ("Is the inductive approach a better technique for teaching principles? Does it have a desirable effect on attitudes?), there is no argument, from the perspective put forward in *The Act of Discovery,* that an inductive approach has a desirable effect on attitudes. Inquiry/discovery learning has been specifically designed to create autonomous and self-propelled thinkers. As far as the teaching of principles is concerned, current cognitive research suggests that Bruner's intellectual potency and conservation of memory are a consequence of constructive activities. Children and adults alike are builders of knowledge structures. "To know something is not just to have received information but also to have interpreted it and related it to other knowledge. To be skilled is not just to know how to perform some action but also to know when to perform it and to adapt the performance to varied circumstances" (Resnick and Klopfer, 1989, p. 4). As a consequence of this view, any instructional activity that broadens and refines students' knowledge structures and helps them to monitor and guide their own thinking and learning should be encouraged. This is not to suggest, however, that an inductive approach is the better technique for the teaching of principles. The section outlining the philosophical and epistemological arguments to inquiry/discovery learning will be more informative with regard to this particular issue.

It is important to note that Bruner's operational definition of discovery is not restricted to objects, events, phenomena, and ideas previously unknown to humanity. Discovery, he writes, "includes all forms of obtaining knowledge for oneself by the use of one's own mind" (1961, p. 22). This is normally understood as being what by Renner and Ragan interpret it to mean when they state:

> We cannot, therefore, expect the children in elementary-school classes to make original contributions to the accumulated scientific knowledge of the world. What will be found, no doubt, is already known and probably found in some textbook... In short, do not expect your pupils to discover something new. You can expect the children in your classes, however, to discover things which are new to them or to obtain insight about a given topic for the first time (1968, pp. 84-85).

Though it is seldom acknowledged in the elementary school science education literature, Bruner was much more thoughtful and definitive in his definition of discovery. He expands on the all too familiar dictum stated above with the following:

> First, let it be clear what the act of discovery entails. It is rarely, on the frontier of knowledge or elsewhere, that new facts are "discovered" in the sense of being encountered as Newton suggested in the form of islands of truth in an uncharted sea of ignorance. Or if they appear to be discovered in this way, it is almost always thanks to some happy hypotheses about where to navigate. Discovery, like surprise, favors the well prepared mind. In playing bridge, one is surprised by a hand with no honors in it at all and also by hands that are all in one suit: one must know to be surprised. So too in discovery. The history of science is studded with examples of men "finding out" something and not knowing it. I shall operate on the assumption that discovery, whether by a schoolboy going it on his own or by a scientist cultivating the growing edge of his field, is in its essence a matter of rearranging or transforming evidence in such a way that one is enabled to go beyond the evidence so reassembled to additional new insights. It may well be that an additional fact or shred of evidence makes this larger transformation of evidence possible. But it is often not even dependent on new information (1961, p. 22).

With this statement, the reader is advised not to expect something outside the learner's head (mind) to be discovered. Discovery is a product of cognitive restructuring (Bruner, 1966b, p.

105). Shulman (1968, p. 35) submits the following interpretation: "For Bruner... discovery involves an internal reorganization of previously known ideas in order to establish a better fit between those ideas and the regularities of an encounter to which the learner has had to accommodate."

JOSEPH SCHWAB

The subtle references by Bruner (in the 1961, excerpt above) to the invention of conceptual structures or guiding principles, the conceptual organization of data, and the interpretation of data by means of the conceptual principles of an inquiry were, by contrast, made lucid and unequivocal by his contemporary, Joseph Schwab (1960, 1962a, 1962b). Schwab was interested in designing science curricula that would not only expose what would become the "nonscience public" to the nature and consequence of scientific research but would also supply the United States with fluid enquirers[6] and original engineers (1960, 1962a). He believed this could best be accomplished through efforts to "teach science as enquiry."

Schwab's enquiring curriculum called for changes in both the high school science laboratory and classroom. The laboratory was to be converted from a place where learned statements were illustrated (*cf.* verification experiments/activities) and perception of phenomena was focused on terms and concepts previously taught to a site "where nature is seen more nearly in the raw and where things seen are used as occasions for the invention and conduct of programs of inquiry" (1960, p. 9). Schwab argued for termination of the bifurcation of school science, that is, erasure of the distinction between mind and hand, and he endorsed the use of more permissive and open[7] "invitations to enquiry" (1962a, p. 55). He wanted teams of students to encounter phenomenon, discuss possibilities, debate the feasibility and validity of different problems, consider methodologies, apportion responsibility, write reports, account for/resolve discrepancies, and arrive at consensus. "All these things," he writes, "are part and parcel of enquiry as it actually occurs..." (1962a, p. 56).

In the classroom, away from the activity of enquiring occurring in laboratories, students were to engage in what Schwab termed "secondary enquiry" or "enquiry into enquiry." Using original papers and actual reports of scientific enquiries as well as climactic narratives,[8] multilinear expositions,[9] or the traditional rhetoric of conclusions,[10] Schwab wanted students to come to know science as enquiry through their discussion of, and enquiries into, these materials. Students, guided by the teacher, were to become skilled in the art of reading and interpreting these papers/reports and in their analysis and evaluation of the formulations of problems, experimental patterns, and interpretative processes by which the conclusions had been reached. Instruction, as a consequence, was not only to show science as a process of enquiry, but teaching, and learning, were to occur through, and by means of, public enquiry, or discussion. This is the meaning that Schwab hoped to convey when he spoke about the need to teach science as enquiry.

Schwab, moreover, was careful to specify what he meant by discussion in the enquiring classroom. He writes,

> Such discussion is concerned with the elucidation, the understanding, and the attempt at critical evaluation of the materials at hand. It is not a forum for irresponsible expression by students of their uninformed opinion on the subject. Neither is it the occasion for mere quizzing about the surface content of the readings. Rather, it treats the materials read as reports. Questions concern the actions, judgments, and decisions of the scientists which the book or lecture described (1960, p. 10).

As a method of instruction, discussion is essential to Schwab's secondary enquiry. It conveys information, develops the habits of inquiry, evokes active engagement, and is a means for cooperative learning and collaborative work.

F. JAMES RUTHERFORD

F. James Rutherford, in a 1964 article published in the Journal of Research in Science Teaching, suggested that the phrase, teaching science as inquiry, was being interpreted, and therefore employed by teachers, in two distinctly different ways. He referred to these dissimilar methods as "inquiry as content" and "inquiry as technique," and drew the following distinction:

"inquiry as it appears in the scientific enterprise... and using the method of scientific inquiry to learn some science" (p. 80).

There is not sufficient information provided by Rutherford to know whether inquiry as pedagogic technique is to be applied to Dewey's reflective action on the world, Bruner's discovery learning, and/or the laboratory component of Schwab's enquiring curriculum. Given his introductory paragraph, however, we do know that these are methods and approaches to which Rutherford is not opposed. He simply recommends that discourse in regard to inquiry in science teaching be focused upon *scientific* inquiry, and offers the following justification:

> ...if all that was intended by the inquiry method is that we should encourage a student to be inquisitive, curious, to ask questions, and to try to find answers for himself, then we are advocating no more that what good teachers have long believed in and practiced (1964, p. 81).

Inquiry as content, by contrast, is described as "operat[ing] on the premise that the concepts of science are properly understood only in the context of how they were arrived at and of what further inquiry they initiated" (Rutherford 1964, p. 81). While this may well be a watered down version of Schwab's inquiring curriculum, the point Rutherford is attempting to make is that in the teaching of science, the conclusions cannot be divorced from the process which led to them. He goes so far as to state, "To separate conceptually scientific content from scientific inquiry is to make it highly probably that the student will properly understand neither" (p. 84).

Unlike Schwab, Rutherford does not believe that inquiry as technique is absolutely necessary for understanding inquiry as content. He does, however, caution that progress toward teaching science as inquiry will be negligible if teachers do not acquire a thorough grounding in the history and philosophy of science.

Inquiry - As Used in Three NSF Supported Elementary School Science Curriculum Development Projects

While Bruner, Schwab and Rutherford were putting their thoughts on paper, the pre-college curriculum reform effort supported by the National Science Foundation (NSF) in the

United States was in full swing. The initial project, which began in 1956 with a grant to the Physical Science Study Committee (PSSC), concentrated on improving the course content of high school physics. The direction this improvement was to take is illustrated in the following description and quote:

> A concerted effort was made to present the scientists' current knowledge about the subject and the ways of obtaining scientific knowledge. This resulted in a general approach in the textbook discussions and problem exercises that invoked the students' reasoning and analytical processes. In addition, investigatory laboratory activities were designed to integrate with the inquiry approach and discussion in the textbook (Klopfer and Champagne, 1990, p. 138).
>
> Reformers wanted students to become scientific, not just learn science (Matthews, 1994, p. 25).

With the successful launching of Sputnik I, the NSF extended its support to universities, colleges, and professional scientific societies interested in developing instructional materials for secondary-level courses in chemistry and biology. By the time Rutherford's JRST article and the text of Schwab's 1961 Inglis Lecture hit the presses in 1964, eleven different high school science curriculum development projects were either in commercially published or extended trial versions.[11] The college-level scientists who were directing the NSF curriculum reform projects had also turned their attention to elementary school science and produced nine science programs[12] that aimed to "bring elementary school children into contact with scientists' approaches in investigating the natural world" (Klopfer and Champagne, 1990, p. 145). Of these nine new curricula, Science: A Process Approach, Science Curriculum Improvement Study, and Elementary Science Study, described below, were the most widely adopted, with an estimated one million student users each (p. 141).

SCIENCE: A PROCESS APPROACH (SAPA)

There is joy in the search for knowledge; there is excitement in seeing, however partially, into the workings of the physical universe and the biological world; there is intellectual power to be gained in learning the scientist's approach to the solution of human problems. The first task and the central purpose of science education is to awaken in the child, whether or not he will become *a professional scientist, a sense of the joy, the excitement, and the intellectual power of science* (Sears and Kessen, 1964, p. 4).

Science: A Process Approach, 1963-1974, is a complete K-6 program developed by the Commission on Science Education of the American Association for the Advancement of Science. It is based on the conviction that "science is best taught as a procedure of inquiry" (Sears and Kessen, 1964, p. 4). Accordingly, young children should be engaged in doing science to learn, through first hand experiences, the procedures and attitudes of scientific study. Robert Gagne, one of the designers of SAPA, writes:

> The most striking characteristic of these [SAPA] materials is that they are intended to teach children the processes of science rather than what may be called science content. That is, they are directed toward developing fundamental skills required in scientific activities. The performances in which these skills are applied involve objects and events of the natural world; the children do, therefore, acquire information from various sources as they proceed. The goal, however, is not an accumulation of knowledge about any particular domain...but competence in the use of processes that are basic to all science (1971, p. 452).

The fundamental skills Gagne makes reference to are the components of scientific inquiry: "the complex set of skills a scientist uses in conducting a scientific investigation" (AAAS/Xerox, 1967a, p.3); "the procedures that give rise to knowledge and define its meaning (Hurd and Gallagher 1967, p. 35). These components of scientific inquiry, derived through task analysis, are identified as primary and integrated process skills (Esler, 1973, p. 107) by the SAPA developers who asked practicing scientists questions related to how they work (Atkin, 1968, p. 8). The primary skills are the processes of observing, using space/time relationships, classifying, using numbers, measuring, communicating, predicting, and inferring. The integrated skills are the processes of controlling variables, interpreting data, formulating hypotheses, defining operationally, and experimenting. To help children acquire greater sophistication in the use of the processes of scientific inquiry, the thirteen primary and integrated science process skills are broken down into a number of component skills, or intradependent subskills for instructional purposes. The subskills for each process are arranged in a simple to complex hierarchy[13] and presented in modules with a prescribed sequence of fairly scripted lessons. The position of a subskill in the SAPA hierarchy determines a module's placement in the program's seven grade specific parts (A through G) with those closer to Gagne's "terminal capability" being encountered in Part F and Part G. Behavioral objectives accompany each module activity and advise the teacher what the individual child should be capable of accomplishing after successful completion of an exercise. "Appraisals" determine whether a majority of the children in a class have satisfactorily attained the objectives. "Competency Measures" are used to evaluate the achievement of individual children.

Part A of the SAPA program attempts to make children in kindergarten more attentive to, and sensually aware of their environment. The modules' activities focus upon the process of observing (seeing, smelling, touching, tasting and hearing) and introduce children to three "tools of description" - using space/time relationships, using numbers, and measuring (AAAS/Xerox, 1967b). These tools "increase the child's ability to describe what he has seen" (David Butts 1996, as cited in Renner and Ragan, 1968, p. 281) and enable simple classification based upon similarities or differences in gross or measurable characteristics.

The school year begins with module a, Observing 1 (*Perception of Color*), and the teacher is expected to proceed through the following sequence of modules (AAAS/Xerox, 1967b):

b Using Space/Time Relationships 1 (*Recognizing and Using Shapes*)
c Observing 2 (*Observing Color, Shape, Texture, and Size*)
d Classifying 1 (*Classifying Leaves, Nuts, or Shells*)
e Observing 3 (*Observing Temperature*)
f Using Numbers 1 (*Sets and Their Members*)
g Using Space/Time Relationships 2 (*Recognizing Direction*)
h Using Space/Time Relationships 3 (*Observing Movement*)
i Observing 4 (*Perception of Sound*)
j Observing 5 (*Observing Color Changes*)
k Measuring 1 (*Beginning Measurement - Comparing Lengths*)
l Using Numbers 2 (*Order Properties*)
m Using Space/Time Relationships 4 (*Spacing Arrangements*)
n Observing 6 (*Observing Solids Changing to Liquids*)
o Using Space/Time Relationships 5 (*Shapes and Their Components*)
p Using Numbers 3 (*Numerals and Order*)

- **q** Observing 7 (*Perception of Odor*)
- **r** Observing 8 (*Perception of Taste*)
- **s** Classifying 2 (*A Purpose of Classification*)
- **t** Using Numbers 4 (*Counting and Numerals*)
- **u** Using Space/Time Relationships 6 (*Recognizing Time Intervals*)
- **v** Classifying 3 (*Classifying Animals*)

In Part B, the process of communicating is presented, and children in first grade become involved in activities that continue the elaboration and development of the five basic science process skills begun in kindergarten (AAAS/Xerox, 1967c). During the school year, the teacher works through twenty-six modules. These are Classifying modules **a** and **i**,[14] Using Space/Time Relationships modules **b**, **c**, **q**, **s**, and **t**,[15] Measuring modules **d**, **j**, **l**, **n**, **u**, and **z**,[16] Using Numbers modules **f**, **k**, and **r**,[17] Observing modules **e**, **g**, **m**, **o**, and **v**,[18] and Communicating modules **h**, **p**, **w**, **x**, and **y**.[19]

As in kindergarten, where "activities designed to develop capabilities in one process contribute to the child's capabilities in other processes," the teacher does not complete the modules associated with one particular process skill and then move on to the activities in modules designed to enhance the use of a different process skill (AAAS/Xerox, 1967a, p. 4). Rather, as the bold lowercase letters above indicate, s/he follows the hierarchy chart, moving the children back and forth between the five process skills (**a** to **b** to **c** to **d** and so on) – each module of activities building upon the complexity of those it succeeds. The skills, as a result, are interdependent and not taught in isolation of one another.

What's more, a process skill is not developed in one specific context or within the activities derived from a particular field of study (*i.e.* mathematics, physical science, biological science, social science, or earth science). Classification, by way of illustration, begins with children discussing perceptible characteristics of leaves and sorting leaves, nuts, or shells with respect to one conspicuous attribute (Classifying 1, Part A). In Classifying 2 (Part A), the objective is to explain the purpose of classification. Children are asked to make up sets of objects that are red in colour, that can be used to write, that can fit into a paper bag, or that will fit through the hole in the lid of a box. The gross physical and behavioral characteristics of common animals are used to construct a single-stage classification system in Classifying 3 (Part A). Following a discussion of the similarities and differences between live animals (Activity 1) and animals at different stages in their development (Activity 2), children are encouraged to discuss and describe illustrations of a hen, chick, turkey hen, turkey chick, lioness, cub, doe and fawn and to arrange the illustrations in groups or two and groups of four (Activity 3). The development of this process skill continues in Part B with two exercises that help children to notice the observable differences between living and nonliving things (a toy turtle and a living turtle, and the animals, plants, water, sand, shells, marbles and coral that will be used to establish a classroom aquarium), to sort playground/school-ground objects as either living or nonliving, and to recognize and describe variations in objects and organisms of the same kind (pictures of dogs, pictures of cats, peanuts in the shell, flowers of the same species, leaves of the same species, and pictures of insects of the same species). In Parts C, D and E, the children develop a simple classification key and use it to place new aquatic organisms in appropriate categories (Classifying 6, Part C); use physical characteristics to classify matter as solid, liquid or gas (Classifying 7, Part C); construct a twelve-hue color wheel (Classifying 8, Part C); separate and classify the components of several mixtures (Classifying 9, Part C); devise punch cards to store and retrieve information (Classifying 10, Part D); and use a punch card information storage system to identify unknown minerals (Classifying 11, Part E).

Thus, a particular process skill is developed in a variety of contexts that utilize facts, concepts and principles drawn from biology, physics, and chemistry. Notwithstanding, the project's emphasis is, without fail, process. Livermore (1964, p. 273) offers the following analogy: "*In Science- A Process Approach*, the processes are the warp on which the woof of content is woven," This image is elaborated in a 1969 paper co-authored with Mayor when they write,

> A particular process skill can be developed using content from different fields. Skill in observing and describing change, for example, can be developed equally well with an expanding balloon, a melting ice cube, or a moving animal. It is to give children experience in content from different areas of science rather than because certain topics are considered important for children to "know about," that the science content is drawn from the physical and biological, earth science and behavioral science (Mayor and Livermore 1969, reprinted in 1972, p. 357).

The focus of Part B is upon change - its detection and description. Children compare popped and unpopped kernels of corn, the size and shape of water soaked and unsoaked bean seeds, the cooked and uncooked leaves of red cabbage, and so on. They distinguish between the changes in weather conditions, record the height of mung bean seedlings, describe the observed changes when a moving object collides with a stationary object, discuss the color changes that occur when ammonia, baking soda or vinegar is added to boiled cabbage water, and the like (AAAS/Xerox, 1967c).

In Part C, the processes of observing, measuring, using numbers, classifying, communicating and using space/time relationships continue to be developed and refined. In addition, four of the twenty-three modules designed for this level engage children in activities that require them to make and test predictions or identify explanations as inferences (AAAS/Xerox 1967d). With the introduction of these two processes, Renner and Ragan (1968, p. 282) write that "the sense of communication is extended to what the observer *thinks* he sees and what he *expects* to see."

Predicting 1, module h, begins with a story of five boys and the number of fish they describe catching. The first boy, Allen, reports catching one great big fish. The second boy, David, caught two. As the teacher continues to relate the story, the children are to supply the remaining numbers of fish caught by Peter, John, and Dick. The teacher discusses with the children their explanations for the numbers suggested. S/he accepts all reasonable ideas and introduces the word prediction with the proviso that it is not a guess but a reason based on data. The children are then involved in activities that require them to collect and graph data and then extrapolate beyond the measurable data represented on the bar graphs. Predicting 2, module w, requires quantitative predicting from data collected by way of the children's opinion surveys.

Inferring 1, module i, begins with a discussion of gift-wrapped packages and how the shape, size, weight, texture, smell, and/or sound emitted by shaking or tilting the package can give some indication of its contents. As before, the teacher is expected to tell the children that the informed guesses they make about a package's contents are called inferences. An inference may prove correct, but owing to the fact that it is made without direct evidence, one cannot be certain until the package is opened. This introductory exercise is followed by experiences with known materials in boxes and experiences with packages containing an unknown object. The objective is to have the children distinguish between what they can observe with their senses as well as statements that are observations (*e.g.* the box rattles) and what they can infer from their observations as well as statements that are explanations of observations (*e.g.* the object is smaller than the box). The activities that make up module n, Inferring 2, help children to begin to see the unreliability of inferences based on inadequate or minimal evidence.

At the end of grade three, when children have worked through the twenty-two modules constituting Part D, the SAPA developers state that the children's competence in all eight of the basic processes encountered in the three previous years "should be at a high level" (AAAS/Xerox, 1968a). The fourth year in SAPA science begins with six activities featuring cartoon illustrations of situations that require children to distinguish between observed and inferred statements, to determine the sense(s) that make possible a specific observation statement, and to examine the basis for each inference (AAAS/Xerox, 1968b). The school year ends with Observing 18, the final module in the Observing process sequence. Children use a dropping machine and other techniques to observe the fall of objects of the same shape but varying weights and the fall of objects of the same weight, but varying shapes. The objectives are to "distinguish whether or not two objects dropped from the same height at the same time strike the floor at about the same time," and, with the teacher's guidance to "identify possible causes of the observed differences in falling times of objects that do not strike the floor at the same time when dropped simultaneously from the same height" (AAAS/Xerox, 1968c). Inserted between these two modules are activities that, among others, involve children in interpolating from their graphed data of the bounce heights of different balls, dividing to find rates and means, testing inferences about the displacement of water by air, reporting the procedures and results of an investigation on the sedimentation of a suspension, drawing three dimensional shapes with all edges visible, predicting the burning time of a candle when the volume of the glass jar used to smother it is varied, and studying transpiration in plants (AAAS/Xerox, 1968a).

In fourth grade, modules with titles like *Rolling Cylinders*, *Guinea Pigs in a Maze*, *Conductors and Nonconductors*, and *Living Things Are Composed of Cells* are used to teach children about controlling variables, interpreting data, formulating hypotheses and defining operationally, respectively (AAAS/Xerox, 1968d). According to the literature accompanying the package of teacher materials for Part E, these four, more complex and integrated processes of scientific activity account for sixty percent of the time set aside for teaching the SAPA program. Part E marks the end of all modules centered upon one basic process skill (*i.e.* Using Space/Time Relationships, Classifying, Using Numbers, Measuring, Communicating, Predicting, and Inferring).

The integrated processes introduced in Part E are the focus of the eighteen Part F modules (AAAS/Xerox, 1970a). Children in the sixth year of the SAPA program (grade five) formulate and test hypotheses to explain data collected in exercises where balanced levers, the dissolution of solids in water at different temperatures, and the reaction of classmates to a PTC (phenylthiocarbamide) taste test are studied. Gnomons (shadow sticks), shadow paths, compasses and protractors are used by children to construct operational definitions of true north, magnetic declination, and magnetic north, while operational definitions furnished by the teacher are used to identify and name parts of familiar plants and bean seeds and to study the relationship between inertia and mass. The remaining twelve modules, rooted in chemistry, biology, earth science, physical science, or mathematics involve children in studies where they control variables and/or interpret data. The activities are as uncomplicated as using a transparent ruler to measure the field of vision of a compound microscope so that sizes of small objects (small insects, a strand of hair, grain of sand, algae, elodea leaf sections, the epithelial cells of an onion, and scales from an insect's wing) can be calculated, and as complex as learning how to express a measure of chance that a specified event will occur in situations that illustrate theoretical probability (tossing coins, inheritance of individual traits, gender at birth, gender and birth order of families, and spinning a four-sided top to move in a game) and empirical probability (sampling to estimate the number of bean seeds in a jar, people listed in a telephone book, words in a book, half-tone dots in a newspaper photograph, salt crystals in a box of salt, and threads in a square meter of cloth).

Included in Part F as "Supplementary Exercises" are a model building activity based upon children's observations of closed "push-rod boxes" and an introduction to scientific notation using large numbers of beads, pulsebeats and respiration, and glurks – imaginary animals whose population doubles each dawn. This level of the SAPA program also acquaints children with printed accounts of two scientific experiments adapted from papers published in *Science*. Each child is to read through "The Reaching Response of Kittens" and name the variables with which the scientist has worked. At a later date, children are expected to identify the controlled variables as well as the hypothesis being tested in a reading titled "Gibberellic Acid and Plant Growth."

The final level of the SAPA program, Part G, is comprised of nineteen modules, two reading exercises, six reading tests, and a supplementary exercise on the inheritance of a recessive characteristic (vestigial wings) in a second generation cross of fruit flies. The first five modules continue the focus of Part F. Modules a and b engage children in activities that require them to use experimental data to reconstruct operational definitions. In module c, children watch a demonstration of the solubility of copper sulfate in water and its precipitation by isopropyl alcohol and discuss their observations. This is followed by two activities where groups of children (1) predict and then measure the effect of the volume of isopropyl alcohol added to a copper sulfate solution (is a precipitate formed; what is the mass of the precipitate) and enter their results on a SAPA prepared data sheet and (2) test the effect of manipulating the variables, kind of alcohol (isopropyl, ethyl, and methyl) and kind of solid (alum, sodium bicarbonate, and sodium chloride), on the amount of solid that precipitates from solution and enter the data collected from these tests on data sheets of their own design. Errors in perceptual judgment created by optical illusions, particularly the Muller-Lyer illusion, are used to formulate and test hypotheses in module d. In module e, children are given copies of photographs of the moon's surface to interpret. The remaining fourteen modules, f through s, provide children with experiences in what the SAPA developers designate as the "experimenting sequence."

The experimenting sequence begins with the identification of words in need of operational definitions and the construction of operational definitions given a statement to be tested. Successive modules ask children to name responding (dependent) variables and to demonstrate how a responding variable is to be measured, to name the independent variables and to demonstrate how each independent variable is to either be manipulated or held constant, to describe how the collected data either support or do not support a given hypothesis, to construct a test of a given question or hypothesis, to construct an hypothesis given a set of observations, and to revise an hypothesis when collected data do not support it. The experimenting sequence culminates with pairs and/or groups of students carrying out their own investigations of specified phenomena (AAAS/Xerox, 1970b).

In general, the SAPA lessons, which emphasize direct and open-ended experiences[20], involve the identification of problems (by the teacher using the SAPA materials), discussions that enable the children to make their knowledge and understanding of the problem(s) public, the giving of hints and directions so that the children are guided to finding solutions, generalizing experiences,[21] and final group appraisal problems that, by design, require the children to apply the skills they have just become adept at using (AAAS/Xerox 1967a, 1967b,; Blough and Schwartz, 1974, p. 53).

The suggested strategies and approaches to be used by teachers of the program are outlined in what the developers call "The Teacher Text." This is a boxed set of printed booklets that describe the SAPA program and provide the teacher with much of the information the developers believe s/he must have to teach school science well. The booklets are colour coded, each of the thirteen processes being designated by a specific colour, and specific to a particular exercise (what I have been calling a module). Thus the name, "Exercise Pamphlet." A pamphlet includes a rationale for teaching the skill, a sequence chart that shows how the skill being taught is related to other skills, new vocabulary, the instructional procedure for each activity, a description of the generalizing experience, the group competency measure with the acceptable behavior and, where required, the individual competency measure with the acceptable behavior, and a list of the necessary materials that were supplied either by the teacher or by Xerox in Standard or Comprehensive SAPA Kits. These kits contained sufficient quantities of equipment and instructional materials for a class of thirty students. They were "ready made," and the materials were organized in a storage container of corrugated cardboard or high-impact styrene with drawers that were colour-coded by process and labeled with letters that corresponded to the exercise pamphlets.

Regardless of the activity or module, the purpose of Science: A Process Approach is always to teach children "a structured and directed way of asking and answering questions" by giving each child "the chance to work as a scientist by carrying out the kinds of tasks which scientists perform" (AAAS/Xerox, 1967a, p. 4). Competence in the processes of scientific inquiry, however, is not limited to experiences in school science or in the discipline of science. According to the program developers, "the processes of scientific inquiry, learned not as a set of rigid rules but as ways of finding answers, can be applied without limit. The well taught child will approach human behavior and social structure and the claims of authority with the same spirit of alert skepticism that he adopts toward scientific theories" (Sears and Kessen, 1964, p. 4). That is to say, the processes of scientific inquiry are considered to be transferable "intellectual skills" (Gagne, 1973, p. 204).

SCIENCE CURRICULUM IMPROVEMENT STUDY (SCIS)

One of the goals of SCIS is to teach children to look at natural phenomena from a modern scientific point of view. This viewpoint may be quite different from the "commonsense" orientation prevalent in a particular culture, and the concepts developed spontaneously by a child from his interpretation of his own experience may not be compatible with modern scientific concepts. For example, a child, from his experience, might not consider air to be matter (a material object). It is unreasonable to assume that children will spontaneously change their viewpoint and learn modern scientific concepts. It is therefore necessary to introduce these concepts to them. For such concepts to have any meaning, however, the children must have had certain previous experiences, which can be interpreted or reinterpreted in the light of these new concepts; for example, children who have felt the wind have had an experience to which they can relate the concept that air is matter. Further understanding and full significance of this concept can then be achieved when children are given the opportunity of discovering that new observations can also be interpreted in the light of the new concept. This approach allows children to use their creativity and imagination within a modern scientific framework (Jacobson and Kondo, 1968, pp. 41-42).

The Science Curriculum Improvement Study, 1962-1974, was developed at the Lawrence Hall of Science at the University of California-Berkeley under the direction of Robert Karplus in an effort to "increase...scientific literacy in the school and adult populations" (Karplus, 1964b, p. 293). Karplus, a professor of theoretical physics, believed that an individual's scientific literacy results from three factors - basic knowledge, investigative experience, and curiosity (SCIS, 1970a, p. 8). He argued, that for young children, science programs built upon vicarious experiences (reading about science, being told about science, or watching a science demonstration) or direct experiences alone, will not, and do not, lead to a realistic and concrete understanding of the phenomena that make up each child's surroundings (Karplus and Thier, 1967, pp. 65-68; Karplus and Thier, 1971, p. 472). In the first instance, the degree of involvement for the child is too low. In the second, where involvement for the child in the science program is at its highest, there is no conceptual structure to give experiences meaning; a scientific perspective through which phenomena can be interpreted is absent. As a consequence, Karplus, by means of The Science Curriculum Improvement Study, aimed to turn the classroom into a laboratory where basic scientific knowledge, investigative experience, and curiosity could be "integrated, balanced and developed through the children's involvement with major scientific concepts, key process-oriented concepts, and challenging problems for investigation" (SCIS, 1970a, p. 8). He writes,

> The function of education is to guide the children's development by providing them with particularly informative and suggestive experiences as a base for their abstractions. At the same time, children must be led to form a conceptual framework that permits them to perceive the phenomena in a more meaningful way and to integrate their inferences into generalizations of greater value than they would form if left to their own devices... A science curriculum should therefore be judged both on the opportunities it affords pupils for having stimulating experiences and on the conceptual hierarchy these experiences nourish (p.8).

Karplus is guided in his thinking by the experimental work at the time on the cognitive development of children. His reading of Joseph McVicker Hunt, Jerome Bruner, Jean Piaget, and Piaget and Barbel Inhelder, causes him to abandon views of fixed intelligence and predetermined mental development. In their stead, he adopts a conception of intelligence as "a hierarchy of strategies for processing information and schemata for assigning significance to information" that is "formed and structured in accordance with the experience of the individual" (Karplus, 1964b, p. 295).

The results of Piaget's and Bruner's clinical studies of children, provoked others to appreciate that intellectual stimulation during the formative years is as important as native endowment in determining the future achievement of each child. Karplus recognizes the implication of this research for education and teaching, and he notes,

> In this view, the contribution that education can make to society is vastly greater than was previously thought possible. The elementary school acquires a particularly deep responsibility, because the child's thinking is especially sensitive to experience as it undergoes a gradual transition from the concrete to the abstract in the age range from six to fourteen years (1964b, p. 295).

The theoretical framework of the SCIS program is distinctly Piagetian (Karplus and Thier, 1967, pp. 19-24 and 35-37; Thier, 1970, pp. 75-107), though Cain and Evans (1979 p. 72) propose that it is "Piagetian as adapted and applied to American education by Bruner and Stendler." Karplus and his associates understand that children, whether inside or outside of school settings, make observations, invent concepts that interpret these observations, and make discoveries that enable concept refinement. These unschooled (*cf.* naïve or alternative) conceptions, however, "reveal a type of natural philosophy – a 'commonsense' orientation popular in the culture at a given point in history," not a scientific interpretation (Atkin and Karplus, 1962, p. 46). "In a small way," Atkin and Karplus explain, "the [classroom] situation is analogous to that of a Copernican teacher instructing his students that the sun is at the center of the solar system when almost everyone else in the society knows that the earth is at the center of the universe."

The problem, from this perspective, then, is not to teach children to invent concepts; they do this quite naturally. Rather, it is to help them to realize that their pervious observations and interpretations can be understood in a different, and more generative way, and to provide the necessary conceptual framework to stimulate their further cognitive development. This is accomplished, Karplus and the SCIS developers propose, by means of guided discovery as depicted in "the learning cycle." Moreover, they submit that the consequence of failing to provide interpretive constructs is the haphazard development of scientific concepts and the generation of invalid generalizations that act as "serious obstacles" to each child's ongoing learning in school science (Karplus, 1964b, p. 296).

The SCIS learning cycle incorporates three stages, or phases, that have been labeled exploration, invention, and discovery. The exploration phase is a period of extensive, open-ended investigation and experimentation, using pre-selected "more or less common materials", with little, if any, specific instruction and minimal guidance (Karplus, 1964b, p. 299; Karplus and Thier, 1967, p. 37). Small groups of children "handle equipment, try out ideas, share ideas and results with each other, and develop new ideas and things to do" (Cain and Evans, 1979, p. 76). This is the period in the cycle where children review and deepen their understanding of previously formed concepts, and, due to the fact that some of the materials are unfamiliar, it is also designed to present children with "some problems with which they cannot yet deal adequately" (Karplus, 1964b, p. 299).

The period of spontaneous learning is followed by a structured teaching phase, called invention. Here, the teacher brings the children together to discuss their explorations and observations. Owing to Karplus' understanding that "spontaneous learning is limited by the child's preconceptions" and "few children can phrase new concepts by themselves" (SCIS, 1970a, p. 14), the teacher is instructed to "invent" a new concept for the interpretation of what the children have seen occurring, and s/he is to guide the children to notice the relationship of their findings to the conceptual invention[22] (Coffman and Karplus, 1968, as cited in Thier, 1970, p. 217).

By invent, the SCIS developers mean that the teacher is to supply a term and a clear and explicit definition of that term, but not in "a complete, definitive, and authoritarian way, for concepts are never final" (Atkin and Karplus, 1962, p. 47). Giving a name to an object or event stems from a belief that "children grasp a stable and usable concept more easily when they have a verbal label which helps them communicate with themselves and with others" (Karplus and Thier, 1967, p. 38).

The conceptual invention is presented to the children as a suggestion; a new way to think about their observations (Karplus, 1964b, p. 299). When the concept has been introduced and defined "as concretely as possible with the help of experimental demonstrations, text material and audio-visual aids," the teacher provides the children with opportunities to use the new concept and encourages them to look for illustrative examples (Karplus and Thier, 1967, p. 38). According to Thier (1970, pp. 140-141), the concept becomes "more real" during these focused experiences, and the children learn that "the invention is a valuable tool for the description and analysis of phenomena." A discussion of the validity of the illustrative examples detected by the children brings the invention phase to a close.

The learning cycle concludes with what is essentially an application phase. The children, in possession of additional materials and equipment, engage in activities, either teacher planned or self-initiated, that enable them to see/discover how the invented concept applies in novel situations and that make it possible for them to discover new and different uses of the concept (Coffman and Karplus, 1968, as cited in Thier, 1970, p. 217). Atkin and Karplus (1962, p. 47) believe this type of discovery is "extremely valuable to solidify learning and motivate the children," and they deem it "essential, if a concept is to be used with increasing refinement and precision." Their position rests on the following premise: "questions of scientific observation are decided by experiment, [and] questions of interpretation are at first decided by preference in the light of past experience and later by the usefulness of the interpretation in generating discoveries" (p. 51).

A large portion of the time devoted to SCIS science is given over to the discovery phase of the learning cycle. The data obtained in these sessions is reported, compared, and analyzed by the children. This is also the period in the program where the teacher helps the children to arrive at interpretations and conclusions and guides them to see regularities and to use these regularities in the building of explanatory models from which predictions can be made (Thier, 1970, pp. 144-146).

The construction of each SCIS unit is informed by the distinction drawn between invention, "the introduction of an interpretive construct," and discovery, "the recognition of the usefulness of the construct" (Karplus, 1964b, p. 299). In this regard, Karplus makes the following comment:

> An important consideration which I believe to be applicable to all future units is this: some things can be discovered by children doing experiments, but some cannot. These latter are the man-made constructs in terms of which he thinks about natural phenomena. The former are the outcomes of specific experiments. To make a discovery, however, certain constructs have to be available to the observer... The creator of a unit has to be clear in his mind what constructs are already available and what constructs must be introduced to enable the pupils to make the discoveries he would like them to make. Once he has decided, the constructs have to be "invented"

> for the pupils near the beginning of the unit so they may be used many times over and at the pupils' initiative before the end of the unit. In subsequent units, the previously introduced constructs serve as a starting point whose incomplete adequacy is revealed by new observations. Another cycle of growth in the pupils' conceptual structure can then commence" (1964b, p. 299).

The SCIS program is composed of thirteen units. The thirteen units form a complete science curriculum for use in the elementary school. One unit, *Beginnings*, is an introduction to science for children at the kindergarten level. The twelve remaining units, listed below, are divided into six, year 1 through year 6, physical science units and six, year 1 through year 6, life science units.

SCIS Physical Science Sequence	SCIS Life Science Sequence
Material Objects	*Organisms*
Interaction and Systems	*Life Cycles*
Subsystems and Variables	*Populations*
Relative Position and Motion	*Environments*
Energy Sources	*Communities*
Models: Electric and Magnetic Interactions	*Ecosystems*

The use of the term "year" as opposed to grade level is a subtle distinction made by the developers of the project who refer to their program as "ungraded" (Suzanne Stewart, 1986, as cited in Thier 1970, p. 215). This, according to Herbert Thier, the assistant project director, is for the purpose of reducing the period of transition at the time of program adoption. "Within the SCIS sequence," he reports, "there are a number of flexibilities as to choice of units at a given grade level..." (Thier, 1970, p. 219). In which case, one need not restrict the use of *Organisms* and *Material Objects* to first grade or *Life Cycles* and *Interaction and Systems* to grade two, and so on.

The concept tying all thirteen units together is the SCIS focus on interaction, "the view that changes take place because objects interact in reproducible ways under similar conditions" (SCIS, 1970a, p. 8). The primary objective of the program, as a result of this focus, is not simply to give children direct experiences with a variety of familiar phenomena in settings that help to develop their observation, manipulative, data collection/recording and communication skills, but to lead them to think of the natural phenomena they encounter in terms of systems of interacting objects or components that do something to one another and bring about change (Karplus and Thier, 1967, p. 15).

Four major scientific concepts, matter and energy, in the physical science sequence, and organism and ecosystem, in the life science sequence, run through the SCIS units and are used to elaborate the notion of interaction. Owing to the program's theoretical underpinnings and the built-in hierarchical levels of abstraction that conform to Piaget's stages of cognitive development, these concepts become increasingly complex as the children progress through the curriculum. It is precisely for this reason that the developers warn against implementing a SCIS unit in isolation from the others or teaching a unit out of its life science or physical science sequence: "The abstractions on the earlier levels have to be grasped before the ones on the later levels can become meaningful" (Karplus, 1964b, p. 297).

Level I in the SCIS hierarchy is adapted to the transition from Piaget's pre-operational thought to concrete operational thinking. First level abstractions are conceptions of matter (living and nonliving objects and materials), of organism (plant and animal; birth and death; growth and development), of conservation of matter (systems), and of regularity and variation. All are directly observable and concrete. Level II corresponds to Piaget's concrete operational period. Second level abstractions are conceptions of interaction (contactual and at-a-distance), of change (evidence of interaction), of population and population interaction (feeding relationships), of environment, of subsystem, of solution, of variable, and of relativity (the position or motion of an object with respect to another object). Level III is adapted to the transition between concrete operational thought and Piaget's formal operational thinking. Third level abstractions are conceptions of energy, of energy transfer, of electric and magnetic interactions, of community (interdependence by way of food-energy relationships), of ecosystem (cycling of materials between organisms and the environment), of steady state, and of equilibrium. All are based upon the more concrete understandings of Level I and Level II (Karplus and Thier, 1967, p. 35; Karplus and Thier, 1971, p. 469; Cain and Evans, 1979, pp. 73-75; Wolfinger, 1984, p. 303).

Along with the major and minor scientific concepts listed above, there are four additional concepts that make there way into the SCIS units. These are property, reference frame, system, and model. They are referred to, collectively, as the process-oriented concepts and are believed to be "at the heart of the processes of observing, describing, comparing, classifying, measuring, interpreting evidence, and experimenting" (SCIS, 1970a, p. 9). The SCIS developers recognize that descriptions, comparisons and classifications are based upon the inherent properties of objects, yet understand that each description or comparison that is made reflects the observer's point of view or frame of reference. They also appreciate that, without knowledge of the real or constructed (model) system/subsystem being investigated, tests of a given question or hypothesis cannot be constructed, variables cannot be controlled, manipulated and/or measured, data cannot be collected, analyzed and interpreted, conclusions cannot be drawn, and predictions cannot be made (SCIS, 1970a, pp. 9-11).

As a result of the curriculum decisions made by the SCIS developers regarding the teaching and learning of scientific and process oriented concepts, the content goals, process goals, and conceptual development goals are "completely interwoven and intermingled" in the program of SCIS activities (Karplus and Thier, 1967, p. 72). This stems from the conviction that "no one ingredient can be isolated from the others as a means for building the science program." Karplus and Thier, in fact, caution that the partition and separation of these goals "usually leads to sterility accompanied by a significant increase in the use of words to talk about science and a decrease in the activities which allow the individual to experience natural phenomena directly".

The first year units will serve to illustrate the manner in which content, process, and conceptual development goals are intertwined. *Organisms* provides children with opportunities to grow pumpkin, mustard, pea and ryegrass plants from seed, to establish fresh and salt water aquaria, and to explore a local area to determine the plants and animals living within it. During the school day, children water plants, feed fish, and record and discuss their observations of these systems. They are also engaged in activities that, among others, encourage them to describe and compare the properties of seeds and seedlings; to investigate the effect of planting depth, substrate, watering, and light on seed germination and plant growth; to arrange plants in order according to height, color, leaf width, stem thickness, or another property; to suggest how a plant bending toward the light can be straightened without being touched; to determine the effect of light on a freshwater aquarium; to carry out investigations that will help distinguish a male guppy from a female guppy; to track changes in guppies born in the classroom aquaria and changes in the eggs laid by pond snails; to observe and report changes in a dead and decaying guppy or snail; to determine the cause of green aquarium water; to filter green aquarium water and predict what will happen when the filtered particles are used to inoculate tumblers of aged tap water placed in the light; to establish an aquatic habitat; to culture *Daphnia* in vials containing algae; to study *Daphnia*'s position in the food webs of freshwater aquaria; to determine the origin of the "black stuff" (detritus) in the classroom aquaria; and to compare plants grown in detritus and sand with plants grown in detritus alone (SCIS, 1970b).

At the end of this and the companion unit, *Material Objects,* where children compare and order, sort and classify objects (tangible pieces of matter) on the basis of their properties and material composition and then change the form, appearance, or phase of these and other objects (SCIS, 1970a), children will have been introduced to twelve conceptual inventions. These are object, property, material, serial ordering, change, and evidence in the physical science sequence, and organism, birth, death, habitat, food web, and detritus in the life science sequence. In addition, they will have begun "to sharpen their powers of observation, discrimination and accurate description" and thereby taken the first step toward systematic investigation of natural phenomena (SCIS, 1970a, p. 12). They will also have begun to perceive the consequences of interactions between living organisms and their environment and the consequences of interactions between nonliving materials (mixing liquids, displacing water with air and air with water, and floating/sinking solid materials in liquid water).

Evaluation in the SCIS program is an on-going process that is not tied to specific behavioral objectives. As children work toward scientific literacy, the teacher uses a variety of sources to monitor their progress. These include observations of each child's work habits, attitudes, and participation, assessment of each child's written work on lab sheets and in science manuals, and on the spot evaluation of the children's responses to convergent and divergent questions.

Each unit in the SCIS curriculum was designed and commercially distributed as a kit that contains all of the materials necessary for teaching the program. The contents of a kit were packages of equipment and supplies, referred to as the equipment kit, student manuals or activity sheets, and a teacher's guide (Karplus and Thier, 1967, p. 140-141).

The equipment kit included all but the most ordinary of the nonliving materials needed to teach a unit to a class of thirty-two students. These materials are sorted and packed into boxes that became drawers in a two or three-tiered shelving/storage unit. Each drawer was numbered, and the number corresponded to a diagram listing the name and quantity of items contained in that drawer. Living organisms studied in the life science units were ordered prior to use and shipped separately.

The student manuals were modeled along the lines of the logbook as opposed to the textbook and contain no scientific information. This, according to Karplus and Thier, was to encourage an approach to science education where children worked directly with materials to make discoveries and gain experience and to curb "[t]he all too common reading about science from a textbook..." (1967, p. 141). The printed student manuals, as a consequence, provided "instructions for carrying out experiments, forms for recording information about experiments completed, and pages which pose problems and encourage discussion..." (p. 141). They were valueless in the absence of SCIS materials and classroom activities.

The guides written for teachers of the SCIS program have been described as "a real 'in-service' education for the experienced teacher and an invaluable 'counselor' to the new teacher (Renner and Ragan, 1968, p. 260). This judgment is in response to the effort made by the SCIS writers to conceive of the guide as a medium of communication between the SCIS staff and the classroom teacher. Rather than merely outlining student activities, stating the objectives to be achieved, listing necessary materials, and providing a glossary of new terms, each guide also suggests to the teacher the strategies to employ, the encouragement to offer, the questions to pose, and the patterns of behavior to embrace if a classroom environment that "will allow the child to achieve the objectives which the materials can lead him to accomplish" is to be established. There are also chapter overviews[23], notes to remind the teacher of the preparations to be initiated in advance of activities, and ideas for optional exploration opportunities. Moreover, each of the three to seven parts that comprise a unit contain several paragraphs of pertinent background information, and each unit guide begins with a four page synopsis of the SCIS conceptual framework and an overview of the program. The program overview includes a description of the unit in question, a list of the concepts to be invented, a brief summary of the preceding units, as well as a description of the companion unit in the biological science or physical science sequence of the program.

The thoroughness of the teacher's guide is rooted in the crucial role ascribed to the classroom teacher by the SCIS project team. Owing to the fact that the teacher is "the adult directly responsible for the presentation of the educational program to the student," they reason that the success of the SCIS program is, in large part, determined by a teacher's actions and attitudes (Karplus and Their, 1967, p. 80). The guide is to insure that these actions and attitudes are informed and guided by an understanding of the content and structure of science and knowledge of how children learn.

Elementary Science Study (ESS)

It is apparent that children are scientists by disposition: they ask questions and use their senses as well as their reasoning powers to explore their physical environments; they derive great satisfaction from finding out what makes things tick; they like solving problems; they are challenged by new materials. It is this natural curiosity of children and their freedom from preconceptions of difficulty that ESS tries to cultivate and direct into deeper channels. It is our intention to enrich every child's understanding, rather than to create scientific prodigies or direct all children toward scientific careers. We want children to be at home with modern technology, not to be intimidated by it. We have tried to incorporate both the spirit and the substance of science into our program in such a way that the child's own rich world of exploration becomes more disciplined, more manageable, and more satisfying (ESS, 1970a, p. 7).

In 1958, a private non-profit organization, the Education Development Center[24], was established in Newton, Massachusetts for the purposes of developing "new ideas and methods for improving the content and process of [science, mathematics and social studies] education" (ESS 1970a, p. *iii*). The Elementary Science Study, 1960-1971, was one of the Center's curriculum development programs, and one of its largest endeavours (Rogers and Voelker, 1970, p. 36). It began when David Hawkins invited a group of curriculum developers to meet and produce equipment for the teaching of science from kindergarten through grade nine. The following year, the ESS team attained NSF funding and began to develop activities, films, and printed materials to support the program's equipment. By the autumn of 1970, fifty-six ESS units had been designed, field tested, revised and published.

The fifty-six units, listed below, represent an array of subjects drawn from mathematics, the earth sciences, the physical sciences, and the biological sciences (Romney, 1971, pp. 7-9).

ESS Units Where the Principle Subject Matter is Derived from Mathematics	ESS Units Where the Principle Subject Matter is Derived from the Earth Sciences
Attribute Games and Problems (K - Grade 9)	*Daytime Astronomy* (Grades 5 - 8)
Geo Blocks (K - Grade 9)	*Mapping* (Grades 5 - 7)
Match and Measure (K - Grade 3)	*Rocks and Charts* Grades 3 - 7)
Mirror Cards (Grades 1 - 9)	*Stream Tables* (Grades 4 - 9)
Pattern Blocks (K - Grade 9)	*Where is the Moon?* (Grades 3 - 7)
Peas and Particles (Grades 4 - 8)	
Tangrams (K - Grade 9)	

ESS Units Where the Principle Subject Matter is Derived from the Physical Sciences	ESS Units Where the Principle Subject Matter is Derived from the Biological Sciences
Balloons and Gases (Grades 5 - 8)	*Animal Activity* (Grades 4 - 6)
Batteries and Bulbs (Grades 2 - 6)	*Animals in the Classroom* (K - Grade 4)
Batteries and Bulbs II (Grades 5 - 9)	*Behavior of Mealworms* (Grades 4 - 8)
Clay Boats (Grades 2 - 6)	*Bones* (Grades 4 - 6)
Colored Solutions (Grades 3 - 7)	*Brine Shrimp* (Grades 1 - 4)
Drops, Streams and Containers (Grades 3 - 4)	*Budding Twigs* (Grades 4 - 6)
Gases and "Airs" (Grades 5 - 8)	*Butterflies* (K - Grade 5)
Heating and Cooling (Grades 5 - 7)	*Changes* (Grades 1 - 4)
Ice Cubes (Grades 3 - 5)	*Crayfish* (Grades 4 - 6)
Kitchen Physics (Grades 6 - 9)	*Earthworms* (Grades 4 - 6)
Light and Shadows (K - Grade 3)	*Eggs & Tadpoles* (K - Grade 6)
Mobiles (K - Grade 4)	*Growing Seeds* (K - Grade 3)
Musical Instrument Recipe Book (K - Grade 9)	*Microgardening* (Grades 4 - 9)
Mystery Powders (Grades 3 - 4)	*Mosquitoes* (Grades 3 - 9)
Optics (Grades 4 - 6)	*Pond Water* (Grades 1 - 7)
Pendulums (Grades 4 - 9)	*Small Things* (Grades 4 -6)
Primary Balancing (K - Grade 4)	*Starting from Seeds* (Grades 3 - 7)
Printing (K - Grade 3)	*The Life of Beans and Peas* (K - Grade 4)
Sand (Grades 2 - 3)	*Tracks* (Grades 4 - 6)
Senior Balancing (Grades 4 - 8)	
Sink and Float (Grades 2 - 7)	
Spinning Tables (Grades 1 - 2)	
Structures (Grades 2 - 6)	
Water Flow (Grades 4 - 8)	
Whistles and Strings (Grades 3 - 6)	

The individual units are discrete. That is, they are designed to stand alone, not as part of a spiraling science curriculum or particular grade level sequence. Each unit has also been developed with a range of grade levels in mind, not one specific grade level. *Kitchen Physics*, by way of illustration, is a unit intended primarily for children in grades six and seven, but it has been used successfully in both lower and upper grades (ESS, 1974a, p. 3). Moreover, it is not dependent upon *Colored Solutions* (Grades 3-7), *Drops, Streams, and Containers* (Grades 3-4), *or Water Flow* (Grades 4-8) though the teacher's manual states that these are units also providing experiences with liquids (ESS, 1974a, p. *iv*).

The ESS curriculum developers' decision to design materials for a grade range is a result of the approach taken in the conception, planning, and development of a unit and the responses of children and their teachers to the materials during a two to three year period of trial teaching (ESS, 1970a, p. 10). With respect to unit production, Romney writes:

> In developing ESS units, we have not proceeded primarily from theories about the structure of Science or from a particular conceptual scheme of learning; rather we have relied upon the taking of what we thought were good scientific activities into classrooms to see how they worked with children. We have tried to find out what, in fact, six-year-olds, and nine- and ten- and thirteen-year-olds find interesting to explore. What kinds of materials and problems are able to inspire children to look at some part of the world with greater attention and care? What sorts of questions, answers, organizational schemes, equipment, and the like turn out to be most effective in a variety of classrooms? ESS units are, in essence, the result of a search for answers to questions such as these (1971, p. 2).

Each ESS unit begins with an idea, and the idea, following a process of "discussion, consultation, argument, invention and laboratory and shop work," ends up in an experimental teaching guide and trial equipment that are tested in a small number of classrooms by the ESS staff. If the developers, project teachers, classroom teachers, children and observers find that the idea is unworkable, the unit is dropped. If, however, the unit is seen as practicable, it is revised and field tested in a number of cooperating schools, revised again, and sent further afield for trial teaching nation-wide. At the point when scientists and teachers consider that a unit is "scientifically sound, communicates well to teachers and children, and adds a significant dimension to the learning experience," it is released commercially (ESS, 1970, pp. 10-11). The commercial product is fundamentally a compilation of ideas and activities that were, Romney explains, "determined, in large part, by the developers carefully recording and building upon what seemed to interest both the children and the teachers who tried out the activities" (1971, p. 2).

During the period of trial teaching in cooperating schools, the development team was to pinpoint the grade level for which a unit seemed most appropriate. Classroom observations, coupled with the feedback from teachers, consistently revealed, however, "that a unit may work well, though in different ways, with many age and ability levels" (ESS, 1970a, p. 9). This outcome prompted the ESS staff to lay aside "the notion that a given area of inquiry is appropriate for only one age group" and to suggest a range of appropriate grade levels (p. 9): a decision that would not deter them from their plan to produce science materials with "manageable complexity," or richness, so that children from many sociocultural backgrounds and with diverse cognitive, psycho-motor and affective abilities can find something fascinating to explore and "work their own way into a subject, going from simple to complex and from complex to simple" (pp. 3 and 9).

The decision to make self-contained units stems from an awareness of "the enormous variety of schools and school systems" in the United States, and the understanding that "planning a curriculum involves decisions which can be made only with specific knowledge about the teachers, principals, students, parents, and finances in each case" (ESS, 1970a, p. 11). The ESS developers do not believe it is possible for any group, including their own, to design a single curriculum, or one comprehensive program, that will satisfy all of the needs and conditions present in small and large, rural and urban schools scattered throughout the three thousand counties of the fifty states (Morrison and Walcott, 1963, p. 48). Their goal is to develop units that can be used to either custom-build complete science programs for specific schools or supplement science programs in existence (ESS, 1970a, p. 11).

For similar reasons, and in recognition that "learning theorists do not fully understand just what sequences of experiences lead to the kind of changes in children ESS would like to see" (Rogers and Voelker, 1970, p. 39), the unit itself, as represented in the ESS teacher's guide, is merely one of many possible number and sequences of activities. It is intended to give "a feeling for some of the things that have happened in other classes" (ESS, 1970b , p. 8). *Spinning Tables*, for instance, is a unit designed to provide children in kindergarten through grade three with opportunities to "explore the paradoxical behavior of things that move in circles" using manually operated, belt-driven turntables (ESS, 1971d, p. 1). The equipment designed for the unit, available commercially through McGraw-Hill Book Company, includes drive assembly bases (rotating tables) with "O" ring drive belts, pegboard disks, and smooth cardboard disks. It is suggested, in the teacher's guide accompanying *Spinning Tables*, that the children be given opportunities to draw upon the spinning cardboard disks using chalk of different colours, to spin the pegboard disks onto which an assortment of objects including marbles of various sizes and cubes of aluminum, steel and wood have been placed, and to spin covered round, rectangular, and compartmented containers holding either a powder or a liquid. In the introduction to the guide, the authors reveal that the unit worked best, during trial testing, as "an extra activity" – the equipment being accessible to the children the entire school year. Nonetheless, they do not discourage those preferring a more managed, whole class engagement from pursuing such an approach, but suggest that six to eight weeks be set aside so that each child has many opportunities to work with the tables. They continue, in a section titled "A Note on Using the Guide," with the following information and counsel:

> Detailed instructions for teaching formal lessons with spinning tables were purposely not included in this *Guide*. Children learn a great deal just from playing with the equipment. A number of activities are described to help you suggest new avenues of exploration to children who need inspiration from time to time. There is no prescribed sequence to these activities, nor are the activities an indication of all possible investigations with the tables. You and the children will probably think of many other things to do. The more time you spend working with the spinning tables yourself, the more you will be able to help the children in their own explorations (ESS, 1971d, pp. 1-2).

The ESS developers refrain from imposing a specific procedure and order because they believe that "the direction a unit takes should be determined, in large part, by the students, if they are to develop a personal involvement in, and commitment to, their work" (ESS, 1970a, p. 9). Accordingly, "teachers need the freedom to modify the units to suit the requirements of any given class" (ESS, 1970a, p. 9) and should not feel limited by them (ESS, 1969a, p. 2). Individual differences, significant choices, and diversity in the way children spend their time in school are emphasized (Hawkins, 1970d, p. 61).

Each of the fifty-six units consists, at a minimum, of a teacher's guide. The guides range in length from fifteen (*Animal Activity: Activity Wheels*) to over one hundred thirty pages (*Gases and "Airs"*) and are laid out in a more or less fixed format. With the rare exception, this format includes the following: a three paragraph description of the Elementary Science Study; a section which acknowledges those involved in the conception, development, trial testing, and writing of the unit; a table of contents; an introduction to the unit with suggestions for using the guide, determining the age appropriateness of the unit, and teaching and scheduling the unit's activities; a list of necessary materials and equipment;[25] and a description of suggested classroom activities with guidance on how to begin and then maintain the children's explorations. Interspersed throughout are reproductions of children's written and graphic work and/or photographs of children engaged with the materials or equipment specific to the unit. The guides for units in life science provide explicit notes on obtaining/collecting, housing, handling, feeding, and maintaining living organisms. On occasion, a list of useful reference books is included, and with less frequency there exists a section on evaluating. Glossaries are nonexistent, for the following reasoning:

> "To introduce technical terms before the phenomena have been *thoroughly* seen and enjoyed is, in our opinion, a complete mistake" (ESS, 1966a, p. 4);
> "It is part of the ESS approach to avoid introducing the formal names of things and concepts before the reality is understood... We want words to enrich understanding not interfere with - or substitute for - understanding" (ESS, 1970a, p. 8);

Certain ESS units have been developed with supplementary text-based and/or pictorial resources. These appear in a variety of formats including student booklets, picture packets, problem cards, and worksheets (Romney, 1971). *Pond Water*, for example, comes with a set of animal and plant "cards" (photographic enlargements) that identify and describe individual animals and plants that the children may observe in the pond water and mud they collect (ESS 1969b). A set of sixty-three "problem cards" is included in the *Senior Balancing* unit. The cards propose problems that enable children working with the balancing materials to "stretch their imaginations" and to "find relationships that underlie balancing experiences" (ESS, 1970d). Sixteen student worksheets are inserted throughout the *Teacher's Guide for Gases and "Airs."* These one-page worksheets are atypical. Rather than supplying or selecting solutions to questions, the child must carry out an activity (experiment). Once the activity has been performed, the child, as a rule, is asked to respond to questions of the type "what happened?" and "how would you explain what happened?" (ESS, 1967). *Tracks* contains a forty-four page "picture book" as well as a set of 52 cards depicting the prints, drawn to scale, of fourteen animals and a set of ten "mystery track cards" for the children to puzzle over and ascribe to an animal (ESS, 1971a). The *Track Picture Book* is a compilation of black and white photographic reproductions of tire tracks, human tracks, animal tracks, and tracks made in the snow, sand, water and air. The images are interspersed with questions like "What happened here?" and "How were these tracks formed?" (ESS, 1971b). Finally, 16mm silent colour films and 8mm color film loops have been specifically developed to supplement units like *Growing Seeds*, *Eggs and Tadpoles*, *Kitchen Physics*, and *Pendulums*. According to Romney (1971 p. 55), they "bring into the classroom demonstrations and events which students cannot otherwise observe." Unlike the cards, worksheets, booklets and illustrations mentioned above, films and film loops are not included in the unit's kit of materials and resources. They can be ordered at a further cost.

While the units differ in context or style of presentation, subject matter, level of complexity, and duration, the developers claim that the fifty-six units "share a common approach to the teaching of science in elementary schools" (ESS, 1970a, p. 7). The approach is guided by an image of the child as investigator/learner who consciously acts upon the physical world (*c.f.* Piaget) and the teacher as resource person/guide. These are perceptions that originate in learning theories of the time, particularly the conception of knowing and theory of instruction put forward by Jerome Bruner.

Formal evaluation of the children's learning using written examinations is possible when ESS units are utilized, but it is not a method advocated by the developers. Although the teacher provides the materials and equipment and steers investigations of, and with, these resources, the curiosity, effort, and abilities of the children are the determinants of what is noticed, thought about, and explored. As a consequence, the children in a classroom come to understand an idea or concept in unique ways and after varying lengths of exposure (ESS 1970c, p. 10). Rather than expecting children to get a specific idea at a set time and to demonstrate this knowledge by responding to a specific question, the ESS developers suggest that teachers look at other, more complete evidence of learning. This is evidence attained by listening, questioning, and observing – informal techniques of assessment and evaluation built into the teaching of each unit (ESS 1970a, p. 11). They write:

> Since much of what we hope to teach is basic to all learning, and since we offer fundamental intellectual tools and try to promote attitudes of inquiry, it is possible to judge what a child has learned from a given unit not only by the amount of information he retains, but also by his approach to new studies in science and other fields, by the skills he has acquired, and by the habits of mind he evidences (ESS, 1970a, p. 12).

SAPA, SCIS, ESS: Similarities

The curriculum development projects of the 1950s and 1960s were initiated, albeit indirectly, in response to Vannevar Bush's report, "Science - The Endless Frontier," commissioned by President Franklin D. Roosevelt in 1944 (Welch, 1979, p. 283) and the reports of John R. Steelman who chaired a committee for President Harry S. Truman to consider "manpower for research" (Hurd, 1997, p. 29). Steelman's committee of scientists and representatives from science teacher associations linked the economic progress of the United States to increased numbers of scientists, technical workers, and qualified science teachers (Hurd, 1997, p. 29). Bush's writing "established beyond dispute an urgent national need to improve instruction in science and mathematics at all levels of education" (Jackson, 1983, p. 147). Both documents instigated the 1950 founding of the National Science Foundation (NSF), a U.S. federal agency with the mandate to maintain the nation's superiority in science and technology by "guaranteeing that... [the] potential in science research and science education be exemplary" (Duschl, 1990, p. 16).

The first steps taken to strengthen and support scientific research potential, with "potential" construed as the development of future scientists, were at the college/university level.

NSF funds were provided for graduate level scholarships and fellowships and to organize and administer in-service institutes, during the summers of 1952 and 1953, for college teachers to update their science backgrounds (Duschl, 1990, p. 16; Welch, 1979, p. 283). In 1954, the NSF, with the endorsement of the National Academy of Science, provided the University of Washington with a grant of $10,000 to host a pre-college summer institute for twenty-six high school level (Grade 9-Grade 12) teachers (Welch, 1979, p. 283). This pre-college level funding, Welch suggests, was in response to requests for NFS involvement. It was also an acknowledgment of the long-standing belief held by university scientists, industrial scientists, and businessmen in high technology industries like General Electric, Westinghouse, and Dupont that the high school was the weak link in the supply of well trained scientists and engineers (Duschl, 1990, p. 16; Welch, 1979, p. 283). By 1959-1960, the number of pre-college summer institutes had climbed from one to three hundred twenty, sixteen thousand secondary school teachers were annually in attendance, and the NSF's fiscal support for this level of in-service training had risen from its initial grant of $10,000 to $30,000,000 (Welch, 1979, p. 283).

Support for secondary school teachers quickly outdistanced the support for college teachers (Duschl, 1990, p. 19), and with groups like the American Association of Physics Teachers, the National Science Teachers Association, and the American Institute of Physics clamoring for improved school texts and laboratory manuals, it was not long before the NSF became extensively involved with secondary- and elementary-level science curriculum development and implementation (Welch, 1979, pp. 283-284). "The reason...", Duschl writes, "was simple: What good would the training of teachers accomplish if they were sent back to their classroom to teach from outmoded curricula using outdated textbooks" (1990, p. 19). By 1975, eighty percent of the NSF's short-term workshops and in-service and summer institutes were devoted to the implementation of NSF-supported curricula (R.E. Hughes, 1975, as cited in Welch 1979, p. 284).

All of these federally funded curriculum projects, regardless of the level for which they were designed, have a number of characteristics in common. Welch (1979, pp. 287-290) distinguishes between characteristics of the development strategy and the characteristics of the curriculum products as a whole. In the former, he places an infatuation with three to six letter acronyms, thus the generic title, alphabet curricula; the collaborative nature of the projects, with teams of professionals and a prestigious scientist at the helm; the experimental nature of the projects, with summer writing conferences followed by a cycle of trial testing of the materials in a large sample of schools, formative evaluation and revision; teacher-training support; and a commercial publisher or publishers to print and market the instructional materials. For the latter, common characteristics of the curriculum projects, Welch lists variety and flexibility, doing science, and thematic focus.

"Variety and flexibility" refer to the rich variety of integrated learning aids developed by each curriculum group (teacher guides and/or laboratory apparatus, student laboratory manuals, a student text, films, film loops, supplementary readers, overhead transparencies, tests), the variety within a specific course and among the different courses, and the extensive options available to teachers. "Doing science" reflects the position that "...the spirit and method of the parent discipline should be represented in the spirit and method of classroom procedures (Easley, 1959, p. 6). Movement is away from reading about science content and performing verification experiments toward inquiry and research using hands-on/laboratory-based learning experiences. "Thematic focus" illustrates the decision to concentrate upon a few major ideas or basic fundamentals (*i.e.* pure science) and organize curricula around a unifying theme or conceptual structure (*e.g.* the molecular level of biology, Biological Sciences Curriculum Study; chemical bonds, Chemical Bond Approach; the interrelationships of time, space and matter, Physical Science Study Committee). This position was in response to the textbook presentation of science and technology and the superficiality of surveying the knowledge of an entire field in one course. It had the consequence of "minimizing or completely eliminating" personal-social implications and technological applications of science (*e.g.* energy use, pollution, health, care of pets, safety, conservation, foods, agriculture, use of tools, manufacturing, transportation and the like) (see Fensham, 1992; Hofstein and Yager, 1982; Hurd, 1997, pp. 30-34; Klopfer and Champagne, 1990, p. 145; among others).

The common characteristics presented by Welch are attributed to two factors: (1) The Physical Science Study Committee and (2) the guiding principles for project support developed by the National Science Foundation. The Physical Science Study Committee (PSSC) was the first of the NSF-funded curriculum projects to get underway. It officially came into being on November 27, 1956, when Jerrold Zacharias, a physicist at MIT received a NSF curriculum development grant of $303,000[26] to design a new physics course for students attending high school. PSSC physics set the tone and established the method of operation, procedures for the production and testing of material, the course characteristics, and the style that subsequent curriculum reform projects would follow (Duschl, 1990, p. 22; Gatewood and Obourn, 1963, p. 363; Klopfer and Champagne, 1990, pp. 139; Piltz and Sund, 1968).

According to Klopfer and Champagne (1990, pp. 137-138), Zacharias and his project team made a "concerted effort... to present the scientists' current knowledge about the subject and the ways of obtaining scientific knowledge." In so doing, they focused not only on the design of a new high school physics course and textbook (*PSSC Physics*) but also on the development of inexpensive laboratory teaching aids and the production of a series of instructional films and a series of supplementary monographs. The result was: (1) an emphasis on key physical concepts, the building and application of mechanical models of physical phenomena, up-to-date content, and learning what scholarly inquiry is all about; (2) problem exercises, selected and organized to maximize further learning in physics, "that invoked the students' reasoning and analytical processes"; and (3) investigatory laboratory activities that were designed both as genuine inquiries and "to integrate with the inquiry approach and discussion in the textbook" (Easley 1959, pp. 5-9; Klopfer and Champagne, 1990, p. 138).

Initially, as the following excerpt reveals, the guiding principles for curriculum development support outlined by the National Science Foundation prescribed the developmental strategy. Characteristics of the curriculum products were to be determined by each project team.

> The course content improvement project originates with scientists of high professional stature and teachers of recognized competence and experience present evidence that an urgent need for improved subject matter exists in a particular field. Projects are directed by college-level scientists, and grants are made to institutions of higher learning and professional scientific societies. Emphasis is placed on subject matter rather than pedagogy. However, the involvement of teachers at the appropriate level is essential to help insure that the materials developed will be pedagogically sound. Teachers take part in the initial writing and in classroom trials of the preliminary versions of new courses.
>
> Once a grant is made, the scientists who are undertaking the study are given freedom within the pertinent subject-matter area to follow whatever paths will, in their collective judgment, best accomplish the basic objectives of the study (National Science Foundation, 1962 as cited in Klopfer and Champagne, 1990, p. 139).

Three years later, a revised document prepared by the NSF for its authorizing committee in Congress (see Raizen, 1991, p. 16) determined that the guiding principles of the curriculum development program would dictate characteristics of curriculum products as they had, at the outset, directed developmental strategy. These guiding principles were

1. Leadership and work by scientists of stature are essential but all elements of the educational community must contribute - teachers, administrators, psychologists, and other people with special talents bearing on the educational enterprise.
2. Fundamental rethinking of content and approach is needed. Neither the addition of bits and pieces to established programs nor the rearrangement of existing material will suffice.
3. A prime aim is to present the sciences as systems of inquiry rather than simply as bodies of knowledge. To this end curriculum studies lay great emphasis on having students first come to grips with phenomena through laboratory and field experience (preferably directly) but, when necessary, augmented with the range of significant phenomena that can be brought into the classroom through the use of film and television.
4. Laboratory experiences can no longer merely serve to verify previously stated principles. Ways are sought to encourage pupils to discover ideas for themselves and to learn the sciences by developing, so far as possible, the viewpoints and modes of attack of scientists confronting problems.
5. Curriculum content should reflect the structure itself. Program provisions for individual differences should be differences in degree,

not differences in kind. There is not one science for scientists and another for laborers and mechanics. Education in science falls along a continuum, not in storage bins of varying capacities.

6. Current assumptions on when and how to introduce a topic should be scrutinized sharply by specialists experienced in both subject matter (scientists) and learning theory (psychologists and educators). One traditional practice, that of presenting facts of subject information in the same chronological order in which they were discovered historically, has in some instances seemed to be far less than desirable.
7. No single effort or curriculum study, even by a most distinguished group, should, simply because of its existence, preclude independent consideration of the same problems by other capable groups. As has been mentioned, there is no *best* way; only (hopefully) *better* ways.
8. Careful classroom trial of any new materials or sequences of ideas is essential. The acknowledged experts on what science a school student *should* learn are the scientists, the professional educators, and the informed electorate. The ultimate expert on what science a student *can and will* learn is the school student himself, studying that science under whatever conditions are prescribed by those in control of the situation (Gatewood and Obourn, 1963, pp. 361-362).

Klopfer and Champagne claim that the NSF guidelines established "the primacy of the professional scientist." They write: "... the scope, content, approach and design of each project's instructional materials came to depend largely on the vision and sagacity of the scientists involved" (1990, p. 139). The descriptions of SAPA, SCIS, and ESS presented in the preceding sections of this paper, certainly corroborate their position, and, as will be considered later, the judgments and insights (or lack thereof) of these "scientists at the helm" may very well have led to the low adoption rates of the new curricula and the philosophical arguments levied against them.

The majority of authors who discuss the common elements and features of SAPA, SCIS, and ESS generally allude to the strategical and product characteristics considered by Welch (see Bredderman, 1983; Cain and Evans, 1979; Esler and Esler, 1981; Howe, 1993; Hurd and Gallagher, 1967; Kuslan and Stone, 1972; Piltz and Sund 1968; Renner and Stafford, 1979; Trojcak, 1979; among others). The issues being addressed by the scientists, teachers, principals, and educators concerned with the teaching of science in the elementary school, however, were not analogous to the issues confronting the developers of science curricula for the high school. The reform in science education at the elementary school level followed the reform efforts at the secondary school level. For that reason, the questions initiating debate were different. Those cited by Hurd and Gallagher (1967, pp. 29-30) include the following:

> Can real science, science as it is known by scientists, be taught to children?
> Are there certain prerequisites to the learning of science that children must first acquire?
> Can we teach children science with curriculum materials that have a conceptual structure?
> How can science be taught to advance the intellectual development of children?
> What underlying philosophy and what aspects of science should be basic to elementary school science instruction?
> What problems exist regarding instructional materials, such as textbooks, resource units, films, facilities, and equipment?
> How should a national effort related to elementary school science curricula be organized and developed?
> What improvements are desirable and practical in teacher preparation and programs for elementary school science teachers?

From the beginning, it was recognized that the materials for elementary school science would not represent the current methodological and conceptual structures of a discipline that PSSC, CBA, and BSCS project teams had elected as foci and were in the process of attempting to elucidate. Nonetheless, Hurd and Gallagher (1967, p. 30) report that this decision did not preclude teaching scientific concepts and scientific methods of inquiry to children "in ways that are consistent with the meaning and spirit of modern science." What was intended by "*ways* that are consistent with the meaning and spirit of modern science," however, was open to interpretation (italics added). In spite of this dissimilarity, the project team developers, like their secondary level counterparts, reduced the number of content areas or units at a grade level. Field trials in elementary school classrooms had consistently shown that inquiry/discovery learning was a slow process, particularly when compared to traditional and more formal methods of instruction and where depth of understanding was a factor in the former but not necessarily in the latter.

In product characteristics other than thematic focus, the SAPA, SCIS, and ESS projects differ, often to an extreme degree, from the high school curriculum projects. These disparities stem from an unmitigated rejection of the traditional science textbook, an utter commitment to first-hand (individual and/or small group) experiences with materials in more open-ended activities, and a conceptualization of the teacher as a catalyst, guide, consultant and observer as opposed to "a font of knowledge" who, with textbook in hand, tells children about, and/or instructs children in science (Bredderman, 1983; Brehm, 1968; Carin and Sund 1989; Wolfinger, 1984).

In addition, the three elementary school projects share elements that are not commonly associated with the experimental programs developed for secondary school science (Brehm, 1968; Cain and Evans,1979; Carin and Sund, 1989; Howe, 1993; Wolfinger, 1984). First, although the developers of a program may not have specified a particular psychological outlook, the creation of SAPA, SCIS and ESS materials is based on learning theory and incorporates both psychological and developmental principles. Second, owing to the commitment of the project teams to put materials in the hands of children and to have children learn about science by being scientific, success in school science is no longer associated with an ability to read and memorize subject-matter content. Regardless of a child's capacity to make sense of written language, s/he can participate in SAPA, SCIS, and ESS activities. Third, in their attempt to bring children into contact with the approaches for investigating the natural world that scientists use, all three projects moved away from the established emphasis on language and description and became more quantitative in nature. Counting and estimating, weighing and measuring, tabulating and graphing data, and interpolating and extrapolating from measurable data are an integral part of SAPA, SCIS and ESS activities. Fourth, and finally, each of the three projects was commercially marketed as a packaged program that included all of the instructional materials in printed form developed by a project team for the teacher and/or student and sufficient quantities of equipment and manipulative materials for classes of thirty to thirty-two children.

SAPA, SCIS, ESS: DIFFERENCES

The distinctions, drawn between SAPA, SCIS, and ESS run the gamut from significant to trivial. For present purposes, it matters little that approximately one-fourth, one-half, and one-third of SAPA, SCIS and ESS activities, respectively, deal with biologic phenomena (Simpson, 1974), or that the storage requirement for "materials essential to program operation" is 25 cubic feet for SAPA, 4 linear feet for SCIS, and 10-20 linear feet for ESS (Butts, 1969, p. 8). It is significant, however, that although the SAPA, SCIS, and ESS development teams agreed that good school science should be recognizable as science by a scientist (as systems of inquiry that result in bodies of knowledge not simply as bodies of knowledge) and that the intellectual development of the child should be considered in the preparation of instructional materials, dissimilar programs/units of study were designed with respect to the nature and organization of activities, the instructional approach, the evaluation techniques, and the roles teachers and children are asked to perform. These differences, elaborated below, are clear manifestations of (a) each project's psychological foundation and (b) each project team's interpretation of how activity-based school science for young children could most aptly reflect the inquiry and investigation characteristic of science itself.

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...children are not too young to learn about science systematically, just so long as what is presented is understandable to them in terms of their previous knowledge. The difficulty is that whatever the content undertaken, a great deal of instructional time must be spent in providing the child with background knowledge about the methods of science. One can't get very far with force and energy without teaching the child how to make systematic observations, measurements, and inferences. And if one proposes to do this in order to teach force and energy, the question naturally arises whether one might try to teach observation, measurement, and inference with reference to animal digestion, solutions of chemicals, and many other kinds of content. By this line of thinking, one is led back to a "process" view after all (Gagne, 1966a, p. 52).

The Commission on Science Education of the American Association for the Advancement of Science, under the leadership of John R. Mayor, Arthur H. Livermore, and Paul B. Sears, elected to base the SAPA curriculum development project upon Robert M. Gagne's neo-behaviorist psychology and task analysis model of curriculum design. In an address to the Conference on Science Instruction in Elementary and Junior High School sponsored by the AAAS Commission on Science Education in July 1962, Gagne (1963) outlined his position. He began by linking the purpose of a curriculum with "a change of behavior,"[27] thereby grounding curriculum design in the discipline of psychology, continued with a discussion of individual differences, motivation, and learning – three factors identified by psychology as influencing changes in behaviour, and ended with recommendations on the use of this knowledge in planning a curriculum that "is not simply and solely something to be learned," but that "contains within it some powerful factors affecting the ease and rapidity of learning" (p. 31).

For Gagne, an individual is not born knowing or liking science. A science student is dull or bright owing to his/her "history of learning" in science, not genetic factors. His advice, therefore, is not to build a science curriculum for the brilliant student, but to construct a curriculum that ensures that all students have "the kinds of background knowledge which make science easy for them to learn about..." (1963, p. 29). If this is done, it is argued, the problem of motivation is, as well, resolved. For, according to Gagne, the answer to the question "how can the study of science be made of interest to the largest number of students?" should be built into the structures of the curriculum, or how ideas (content) are sequenced. It is his belief that the student learns because s/he likes to learn, and s/he likes to learn because s/he is able to achieve new ideas by combining familiar ideas (p. 30). These new ideas, however, can only be learned if the sequence is right and if the previously acquired ideas can be recalled. The right sequence, Gagne claims, is from the simple to the complex, as "[k]nowledge is a hierarchy of ideas, in which the more complex ones depend for their acquisition on the pervious mastery of simpler ones" (p. 31). The recollection of ideas relies not upon drill but repetition and practice in a variety of contexts.

Gagne closes his address by stating the question he believes the conferees must acknowledge and respond to before curriculum design can begin: "What do we want the student of elementary science *to be able to do*?" The answer is what Gagne refers to as the terminal performance; what the curriculum will enable the student to do after s/he has learned. It is also the behavior from which the design teams will work backwards to discover the subordinate ideas that will determine the content of the curriculum and establish its sequence (1963, p. 31).

Like Dewey, Bruner, Schwab, and Rutherford, enquiry represents "one of the most essential objectives of science instruction" for Gagne (1962, p. 144), and he establishes the terminal capability (possessed by the second- or third-year graduate student) as the disposition "to adopt the procedures of scientific enquiry in response to any new unsolved problem" and the ability "to employ enquiry in the manner so well-known to scientists" (p. 144 and 151). Ostensibly, this sounds very much like Dewey's scientific habit of mind, Bruner's heuristics of discovery, and Schwab's efforts to teach secondary school science as enquiry. Gagne, however, set enquiry (problem solving) as "the terminal thinking process." It is considered to be a "disciplined exercise" that can only be attempted, *after* all the necessary previous steps in learning have been taken (p. 149 and 153). His aim, with respect to science education at the elementary school level (K - Grade 6), is the progressive development of "highly generalized intellectual skills" (1973, p. 209) also referred to as "the methods of the scientist" and the "fundamental competencies which underlie all of learning about science" (1962, p. 152).

These skills/competencies were determined to be the primary and integrated processes, and they are the performance capabilities that Gagne believes will enable the child to gain new knowledge and use it in a meaningful way. Accordingly, he is not interested in directly exposing young children to the conceptual structures of the discipline (*cf.* Bruner and Schwab), or to accumulated bodies of knowledge won through scientific inquiry, or to the networks of inquiry that have led to the construction of specific conceptual schemes, facts, principles, theories and laws (*cf.* Rutherford and Schwab). These, as well as practice in "the methods of enquiry" and independent investigation, are the foci of subsequent (post-elementary) instructional levels (see *The Instructional Basis of Enquiry* in Gagne, 1962, pp. 150-152).

Dewey and Bruner, in contrast with Gagne, have the student begin with problem solving (inquiry) and emphasize "the process of knowledge-getting" (Bruner, 1966a, p. 72). For Dewey this is the process of reflective thinking (the scientific method of knowing). For Bruner this is the process of learning to discover for oneself. Although Gagne would agree with Dewey that critical or incisive knowledge is a prerequisite to successful enquiry – one must be able to discriminate "between a good idea and a bad one, or between a probably successful course of action and a probably unsuccessful one" (Gagne, 1962, p. 149). He doubts that the teaching of thinking strategies or styles will "produce people who could then bear superior problem-solving capabilities to any new situation" (1965, p. 170).

Like Ausubel, who argues that problem solving can not be a genuinely meaningful experience without a foundation of clearly understood concepts, principles, and operations (1964, p. 291), Gagne claims that broad and generalizable subject-matter knowledge is "the basic firmament of thought" (1965, p. 170) and "an essential basis for the practice of the strategies of enquiry" (1962, p. 149). It makes no sense to him that one would believe that a child could think without this knowledge. He suggests that such a conception is comparable to asking a child "to play chess without ever having learned what the rules are" (1962, p. 148) and maintains that the effective problem solver "must somehow have acquired masses of structurally organized knowledge..." that "is made up of content principles, not heuristic ones" (1965, p. 170).

This is to say, if discovery is to occur in the learning of principles and in the solution to problems, it will not take place in situations where reflective thinking or the heuristics/strategies of discovey are applied unless the prerequisite capabilities of broad and critical knowledge have been established (Gagne, 1966b), and these prerequisites, Gagne argues, cannot be picked up incidentally either by practice in inquiry or "by pretending to be a scientist" (Gagne, 1962, pp. 152-153). Moreover, while Gagne acknowledges that discovery as a construct is an essential condition, regardless of instructional level, for several varieties of learning (see Gagne, 1966b), he is adamant that "it should not be equated with enquiry," a terminal capability (Gagne, 1962, p. 149).

So Bruner (1966b), whose educational objectives and conceptions of readiness and transfer differ decidedly from those of Gagne, begins with the complex, and provides instructional situations imbued with incongruities and contrasts (Dewey's pre-reflective situation) that create cognitive dissonance and cognitive restructuring by means of intuition, overt and internalized trial-and error, and discovery (Dewey's reflective though) and terminate in a new level of understanding (Dewey's post-reflective condition). Gagne (1962, pp. 150-152) begins with the simple and carefully guides the student through an orderly sequence of thoughtfully selected content that, by means of the child's own efforts, curiosity and discoveries, will culminate in knowledge of, and competency in, the fundamental skills used by the scientist. Once mastered, the student can begin to acquire the broad and critical knowledge of content and methodology that will make possible the practice of inquiry.

One can infer, from Gagne's (1962, p. 144) brief reference to Schwab's Inglis Lecture and the SAPA inclusion in Parts G and F of printed accounts of scientific experiments adapted from papers published in *Science*, that this level (Grade 6/7 - Grade 11) of classroom instruction will include Schwab's secondary enquiry, or enquiry into enquiry. The laboratory component, as Gagne (1962, p. 151) describes it, consists of "laboratory exercises" that seem to map onto Schwab's first level of openness (*i.e.* problems are posed and methodologies are described, but the relations to be discovered are left open, Schwab, 1960, p. 9). Less prescription, Gagne advises, will result in student activity that is either too narrow in scope or ridiculous, because the student "dosen't *know* enough to behave like a scientist" (*i.e.* s/he hasn't yet learned "to speculate, to form and test hypotheses about scientific problems that are not trivial...").

SCIS and Jean Piaget

The SCIS program intends to nurture the children's wonder, their investigative tendencies, and their abilities for organization in such ways that they can eventually and surely achieve formal

> *operational thinking and the possibilities it holds for intellectual soaring. Beginning at a point where most children are preoperational in their thinking, it provides opportunities to facilitate the progress in the concrete operational thought that is essential if they are to grasp even rudimentary scientific concepts. The intent is not to simply present the concepts to them in pace with their current 'readiness,' but to organize their experience in such a way that readiness for more difficult ideas is constantly enhanced* (Jacobson and Kondo, 1968, p. 28).

The second paragraph of the preface included on page four of each SCIS teacher's guide begins with the sentence, "The SCIS science curriculum is based on current theories of how children learn." As the discussion of the Science Curriculum Improvement Study makes clear, these are the learning theories of Jean Piaget.

Robert Karplus' experiences in elementary school classrooms prompted him to report that most instruction above kindergarten was occurring on a formal level. This, he presumed, was an outcome of stimulus-response theory, and he suggested that it was having the unfortunate consequence of leaving many children unsure about the intent of instruction and dissatisfied with school (Karplus, 1964a, p. 236). Two remedies were proposed. Either teachers could be made aware of Piaget's studies, their outcomes, and their pedagogical implications, or children's ability to use formal operations could be developed. Karplus saw the former as a situation to be addressed and rectified by teacher education programs. The latter was understood to be a curriculum problem that he and the SCIS aimed to correct.

Karplus' reading of Piaget and of Piaget's theory of intellectual development as interpreted by Millie Almy, Jerome Bruner, John Flavell, Joseph McVicker Hunt, and Celia Stendler led him to believe that self-directed, everyday experiences are sufficient to enable children between the ages of five and ten to naturally progress from intuitive and symbolic/representational thinking (Piaget's pre-operational stage) to logical thinking about tangible objects and events (Piaget's concrete operational stage) and for some children between the ages of ten and fifteen to begin to think about hypothetical propositions in a disciplined and logical way (Piaget's formal operational stage) (Karplus and Their, 1967, pp. 21-22). He recognized, however, that the factors Piaget considered to be responsible for the construction and emergence of operational structures (physiological maturation, physical experience, logical mathematical experience, social transmission of information, and equilibration) do not generally lead to the development of a scientific point of view (Karplus, 1964a p. 237; Karplus, 1964b p, 295). He writes,

> Piaget has found that this ability develops in some respects without special instruction, but it does not seem adequate to encompass the results of modern science. Instead, there develops what I would like to call a kind of common sense or natural philosophy. The formal thinking of most youngsters in high school does not in general enable them to recognize the type of relationship one has to recognize when one makes a scientific study (Karplus, 1964a, p. 237).

Karplus sees this state of affairs as being a consequence of the nature and structure of contemporary science, and cites Morris Shamos and C.P. Snow in claiming that "the scientific point of view differs from and goes beyond the natural logic or common sense point of view" in fundamental ways (Karplus, 1964c, p. 79). First, it is no longer possible to talk about science in common sense terms. The careful observation, accurate description and systematic classification that characterized the largely practical sciences (*cf.* natural history) near the turn of the century have, with the discovery of radioactivity, given way to theoretical constructs that have "no common sense counterparts" (Shamos, 1962, p. 8; also see Jacobson and Kondo, 1968, pp. 12-13 and Schwab, 1962b, p. 198).

Second, owing to the theory-ladenness of observation, the non-scientist and the scientist do not perceive phenomena in the same way (Karplus, 1964c, p. 80). According to N.R. Hanson (1988, p. 192), what one sees depends on one's knowledge, experience and theories. "Seeing is not only the having of a visual experience; it is also the way in which the visual experience is had" (Hanson, 1988, p. 190). For this reason, he maintains that the ways in which the layman and the trained scientist are visually aware of the same object are profoundly different.

Third, and finally, "the conceptual structure of science is different from the conceptual structure of common sense" (Karplus, 1964c, p. 80). Karplus points to the dissimilarity between the common sense concern with "purpose and motivation" and the scientific concern with "causes in a more mechanistic way" as one representation of this difference. Schwab's (1962b and 1978) writings on conceptual structures and elaboration of Bruner's concept of the structure of the disciplines, help to validate Karplus' position and make explicit the distinction Karplus recognizes.

Schwab (1978, pp. 264-265) sees commonsense and science as two sorts of knowledge that arise in quite different ways. Commonsense is a collection of "numerous, separate solutions to many different and separate practical problems." It is a catalogue of know-hows. These know-hows, conclusions of commonsense enquiries, are solutions to problems of want and need; problems that "arise from our actions, from our natural endowments (our heredity), and from our situation, our environment." They "are thrust upon us." "We feel them," like the cold, and feeling them "leads us to think them," that is, "to state them to ourselves in a form which can guide us toward solution" (*cf.* Dewey's critical reflection/reflective thinking). Using hunger as the example, Schwab writes,

> ...hunger pangs make us restless; we move; the movements carry us near things whose odors may make us salivate, reach out and grab. Thus, we may be directed toward formulation of practical problems not only by the felt want and need but also by what follows - half-intelligent behavior aimed toward meeting the need (1978, p. 265).

In contrast to commonsense knowledge, scientific knowledge is not a collection of practical, immediate and *ad hoc* solutions to problems, and scientific problems and the enquiries they occasion do not typically arise from actions, natural endowments, or environmental situations and aren't, as a result, either thrust upon the scientist or felt by the scientist. Scientific knowledge originates in thought (Schwab, 1978, pp. 264-265), occasionally in thought that is "bold and imaginative" (Karplus, 1964c, p. 84), and is a "model" constructed to "give meaning" and "bring order to the congeries of disconnected observations" (Bruner, 1962, p. 120) .

According to Schwab (1978, p. 265) science is the slow, systematic, and exhaustive pursuit of the knowledge of the properties and behaviors of a subject matter, where subject matter is interpreted as being "a something to be studied, instead of a need-to-be-filled." For clarification, Schwab draws upon the "catalogue of know-hows" associated with fire and combustibles ("a way to keep warm, a way to get light, a way to tenderize meat") and writes:

> Someone sees, perhaps in a flash of inspiration, that we might better serve our practical needs by being not so practical, so immediate, so *ad hoc*. For, surely, if we turned our attention to fire itself, to the question of what will burn and what will not, how burning starts and what it does, we would be achieving knowledge of a far greater scope and usefulness than by limiting ourselves only to trying to solve practical problems as they arise (1978, p. 265). ...the pursuit of science – of systematic knowledge of subject matter – is more practical than the practical. It arises as an improvement on know-how... Its vast superiority lies in the fact that it enables us to anticipate practical problems, not merely wait until they are upon us. It provides our future as well as our present (1978, p. 266).

In addition, Schwab maintains that "[s]cience begins, or tries to begin in ignorance," and "will, if it can, turn its back on... folk wisdom and folk need" (1978, p. 243). It is, however, guided by the structure of the discipline; "the body of imposed conceptions which define the investigated subject matter of that discipline and control its inquiries" (1962b, p. 199).

This being the case, scientists borrow or invent conceptions of the nature of their subject matter based upon "some metaphysical, preferential, or heuristic committment" to it (Schwab, 1978, p. 240). These conceptions, which precede "sure knowledge," are "developed precisely to make such knowledge possible through research" (1962b, p. 198), and their formation and explication account for "the buried [hidden] four-fifths of enquiry" (1978, p. 239). As Schwab explains in the following excerpt, conceptions are the guiding principles of a scientific inquiry; they not only tell the scientist what questions to ask, what to look for, what will and will not pass for data, but also what meaning to assign the data:

> In short, what facts to seek in the long course of an inquiry and what meaning to assign them are decisions that are made before the fact. The scientific knowledge of any given time rests not on *the* facts but on *selected* facts - and the selection rests on the conceptual principles of the inquiry.
>
> Moreover, scientific knowledge - the knowledge won through inquiry - is not knowledge merely of facts. It is of the facts *interpreted*. This interpretation, too, depends on the conceptual principle of the inquiry (1962b, p. 199).

The conceptual structures define the limits of a study, the compromises made in collecting data, the unverified or unverifiable assumptions formed, and the confidence with which the conclusions can be applied and applied appropriately (Schwab, 1978, p. 238). In addition, the structures enable one to know whether a knowledge statement is a verifiably informative statement as opposed to an emotive statement or a statement of choice, value, or decision, and it is also these same structures that permit one to determine the sense in which an informative statement is "true" (1978, pp. 232-236). Unlike commonsense knowledge, scientific knowledge statements can be quite remote from specific observations. Rather than being "collections of literal statements standing in one-for-one relation to corresponding facts" (1962b, p. 197), the knowledge statements of science "change in the ongoing process of scientific activity," due to the fact that "their meaning depends on all of the other components in the pattern of enquiry from which they arise" (Connelly *et al.*, 1977, p. 16).

In recognizing these discrepancies between problems of want and need (ad hoc solutions; a common sense point of view) and scientific problems (the outcomes of scientific enquiry; a scientific point of view) and the difficulty this divergence causes students, Karplus was determined to devise learning experiences that would "achieve a secure connection between the pupil's intuitive attitudes and the concepts of the modern scientific point of view" (Karplus, 1964b, p. 293) and reduce "the gulf between scientific thinking and common sense thinking" (Karplus,1964c, p. 87). Thus, the laboratory-like classroom; direct experiences with materials, organisms and natural phenomena; a program structured around a hierarchy of abstractions (conceptual inventions) that map onto Piaget's stages of cognitive development and children's intellectual growth; and a pedagogical device (the learning cycle) that facilitates the transition from preoperational to operational thought by leading children to form a conceptual framework that permits the perception of phenomena in a more meaningful (the development of the scientific point of view) and generative way (Bruner's transfer of principles and cumulative constructivism).

The advancement of scientific literacy is the principal objective of SCIS (Karplus, 1964b, p. 293; Karplus, 1964c, p. 86). Scientific literacy is understood by Karplus (1964b, p. 296) as being "a functional understanding of scientific concepts;" the ability to interpret, use, and benefit from the information obtained and/or reported by others. It is believed to be contingent on possession of a conceptual structure and a means of communication. Hence, the position taken by Jacobson and Kondo (1968, p. 18), authors of *SCIS Elementary Science Sourcebook* when they write, "[e]ssentially, scientific literacy involves an awareness of the modes of inquiry in science and some understanding of conceptual structures of science," and the following statement within "The SCIS Conceptual Framework": "A person's scientific literacy results from his basic knowledge, investigative experience, and curiosity" (see p.8 of each SCIS *Teacher's Guide* published in the early 1970s by Rand McNally & Company).

The program's focus on structure and fundamental ideas alongside pedagogical emphases on the unusual experience (Karplus, 1964c, p. 86), development of inquisitiveness, mental flexibility, and skepticism (Karplus, 1965, p. 44), and the facilitation of formal thought ("internalization of symbolic techniques"), point to Bruner's account of what it means to teach science as inquiry/discovery at the elementary school level. Both Karplus and Bruner are engaged in bringing together a theory of knowledge, a theory of development, and a theory of instruction (see Bruner, 1966a, p. 21). Both men understand, as Bruner (1966a, p. 6) declares, that "intellectual development depends upon a systematic and contingent interaction between a tutor and a learner" and each advocates a style of teaching that utilizes the hypothetical mode, as opposed to the expository mode, where "the student is not a bench-bound listener" (Bruner, 1961, p. 23) but "take[s] part in the process of knowledge getting" (Bruner, 1966a, p. 72). It is the degree to which each believes the learner is capable of creating conceptual organizers and discovering interpretive constructs for him/herself that differentiates their approach to instruction.

This is not a problem of semantics, and what it means to discover. Karplus' written texts support Bruner's (1962, p. 118) image of the school as a "special community where one experiences discovery by the use of intelligence, where one leaps into new and unimagined realms of experience...discontinuous with what went before." Karplus, however, is resolute in his belief that "the man-made constructs in terms of which he thinks about natural phenomena" cannot be discovered by children doing experiments in science (1965, p. 14). They must be "invented" so that discoveries can then be made, and invention must be accompanied by substantial guidance and discussion (Karplus and Thier 1967).

Bruner is practically silent on this issue. His scant comments are equivocal. He writes, "Children need not discover all generalizations for themselves, obviously" (1966a, p. 96) and "Insofar as possible, a method of instruction should have the objective of leading the child to discover for himself" (1962, p. 123). He appears to believe that there are "implicit models" in the heads of children that are useful in the knowledge getting process (1966b, p. 105), and that it is the sequence of instruction and the structure and form of the body of knowledge presented that determine a child's ability to recognize (discover) the connections and regularities within the materials they are given the opportunity to explore (1966a) and to achieve new insights (1961, p. 22). Yet, he sees the educational system as social invention – "the sole agent of evolution" (1966a, p. 26), recognizes that the tutor, "equipped with a wide range of previously invented techniques," teaches the child (1966a, p. 6), and pens the following statement that reads like a statement from Karplus:

> I suspect that much of [mental] growth starts out by our turning around on our own traces and recording in new forms, with the aid of adult tutors, what we have been doing and seeing, then going on to new modes of organization with the new products that have been formed by these recodings. We say, "I see what I'm doing now," or "So that's what the thing is." The new models are formed in increasingly powerful representational systems. It is this that leads me to think that the heart of the educational process consists of providing aids and dialogues for translating experience into more powerful systems of notation and ordering (1966a, p. 21).

ESS, JEAN PIAGET, AND JEROME BRUNER

So offered to children, "science" is not an indigestible textbook regime. though it opens books to them. It is not a standardized array of "processes" weighed out and calibrated in units of performance, though it opens the way to the disciplines of method. It is not a hierarchy of eminent "concepts" abstracted from currently fashionable synopses; it is watchful and respectful. rather. of the conceptual powers of children, active or latent, when these are invited to play and observed responsively (Hawkins 1970a, p. v).

In addition to the previously mentioned spiraling curriculum, structure of knowledge, act of discovery in learning, and readiness, Bruner (1962, 1966a) by the mid-1960s, had also written about right-handed and left-handed knowing, intuitive understanding, empty formalism, depth and continuity in teaching, intellectual delight, self-generating intellectual inquiry, the will to learn, and the cycle of learning.[28] As the following excerpts disclose, all of these ideas, in some form, find their way into the ESS approach to elementary science teaching:

> ...we feel that our approach should follow a mixed strategy - one that does not even pretend to be perfectly planned and leaves occasional decisions to chance and to the opportunities of the moment for a particular child, teacher and classroom. Our materials therefore provide situations for traditional, rational, "right-handed" learning and situations suited more to the intuitive, playful, "left-handed approach. They are designed to appeal to all the senses, to the imagination and artistic instincts, and through the wordless experimental equipment as much as through the printed or spoken world (ESS, 1970a, p. 2).
>
> One mandate is imperative for our style of work: there must be personal involvement. The child must work with his own hands, mind and heart (Morrison 1970, p. 111).
>
> The richness of the materials allows for each child to find something fascinating to explore, if he is given the opportunity to choose his own problems and his own way of working on them. The most fruitful investigations and projects have been consistently those which children themselves have initiated and on which they have worked in rather informal and individual ways (ESS, 1971c, p. 2).
>
> Rather than beginning with a discussion of basic concepts of science, ESS puts physical materials into children's hands from the start and helps each child investigate through these materials the nature of the world around him. Children acquire a great deal of useful information, not by rote but through their own active participation. We feel that this process brings home even to very young students the essence of science - open inquiry combined with experimentation (ESS, 1970a, p. 7).

> Children's explorations...can help them understand something of the world around them. A child may not be able to explain the *What's* and *Why's*... If, however, he is free to evolve his own ideas and models, he will also feel free to change them as circumstances require. It is for this reason that there is no attempt to teach concepts, as such... Concepts will emerge - sometimes with faults - but in a matter that allows for change. If a child develops a concept on his own, he is more likely to modify it if it proves not to suffice for changing circumstances. The importance of free play and the need to avoid sustained periods of directed teaching and explanation cannot be emphasized too heavily (ESS, 1976, p. 6).

> ...if you cast your mind over the whole range of abilities and backgrounds that children bring to kindergarten, you see the folly of standardized and formalized beginnings. We are profoundly ignorant about the subtleties of learning but one principle ought to be asserted dogmatically: that there must be provided some continuity in the content, direction, and style of learning. Good schools begin with what children have *in fact* mastered, probe next to see what *in fact* they are learning, continue with what *in fact* sustains their involvement (Hawkins, 1965, p. 7).

> Much of the child's potential for learning is lost as soon as someone else attempts to assume responsibility for that learning (Hull, 1970, p. 147).

Owing to the emphasis on unstructured exploration with highly motivating materials, the ESS approach, popularly characterized as "messing about," is generally perceived as being the archetype of discovery learning. The developers of the ESS units, however, take exception to both designations.

In the article, "Messing About in Science," the free and unguided exploratory work, designated the O Phase, is but one of three major phases determined by the author and one-time ESS director, David Hawkins, to signify good science teaching. The Δ Phase, externally guided and disciplined work with "Multiply Programmed" materials, and the □ Phase, informal and formal lecture/discussion about concepts and theory, are no more or no less important. Hawkins deplores the prevalence of □ styles of science teaching at the expense of O styles, and submits that "no teaching is likely to be optimal which does not mix all three" (Hawkins, 1965, p. 9).

Like the distinction drawn between Karplus and Piaget, there is no consensus among Hawkins and other ESS staff members with respect to the character and extent of external guidance or with respect to the role of scientifically accepted views. At one extreme, teachers select engaging materials, create environments that support children's explorations and reflective thinking, and monitor children's efforts as they work and talk with one another to construct meaning (see Duckworth, 1964 and 1972). At the other extreme, teachers select engaging materials, create environments that promote children's explorations and reflective thinking, monitor and guide children's efforts as they work to extend their experience and relate new information to existing conceptions, and then help them to see that their network of inferences about a concept can be used to interpret analogous situations, make predictions, and solve problems (Hawkins, 1970c). Although subtle, the distinction made between Duckworth, a student of Piaget's, and Hawkins is significant.

For Duckworth, the development of intelligence is a matter of having wonderful ideas. Wonderful ideas are creative intellectual acts that depend upon occasions for having them as well as knowing enough about something to be able to think of other things to do and of other questions to ask: "wonderful ideas build on other wonderful ideas" (Duckworth, 1972, p. 224). They "need not necessarily look wonderful to the outside world" (p. 231), a world that includes the community of scientists and scientifically literate adults, for they are ideas invented by children who have figured something out for themselves (*cf.* Bruner).

Hawkins also sees children as "the prime and indispensable agents of their own learning", but insists that it is an error to relegate teachers to passive, laissez-faire roles when they are indispensable co-agents in learning (Hawkins, 1974, p. 191). This is the perspective made clear in "I, Thou, It", an article on the relationships between children, teachers, and the world, when Hawkins (1970c, p. 47) states, "Without a Thou, there is no evolving". Teachers respond diagnostically and with guidance to behaviours that signal impasses and/or confusion. They help investigators, inquirers, and explorers over humps that they can't surmount through their own resources. Teachers also bring things together in synopsis by means of well-timed lectures. Although dubious of the lecture method when used too early or too often, Hawkins writes:

> I know of no way equal to it, in which doors can be opened and new vistas seen. In the act of bringing precision and coherence to a subject already partly grasped, it transforms the private wanderings of thought into a public order, into what we know and prize as knowledge (1970d, p. 66).

As regards discovery learning, the ESS developers do not deny that aesthetic and scientific discoveries of many kinds will result from children making their own observations, asking their own questions, performing their own experiments and drawing their own conclusions. This is precisely the reason Bruner's "reaching for knowledge with the left-hand" is integrated into the approach: "the left handed is intuitive, hypothetical, playful, witty, imaginative, and sometimes simply wrong" (ESS, 1970a, p. 4). Misrepresentation ensues when discovery is construed as having children detect pre-planned conclusions, when left-handed learning is confused with a discovery method, when a "Discovery Method" is "used as a defense against a lack of subject matter content and as a way of minimizing the importance of preparation"(Hawkins, 1966, p. 10), and learning through discovery is equated with the O Phase as opposed to the O, Δ, and □ Phases whether the children, collectively or independently, develop concepts on their own or with a teacher's guidance. As Hawkins (1965, p. 9) writes: "Theorizing [the □ Phase] in a creative sense needs the content of experience [the O Phase] and the logic of experimentation [the Δ Phase] to support it. But these do not automatically lead to conscious abstract [scientific] thought."

Ostensibly, the ESS project in school science sounds like Dewey's dream of what schools might become: "a genuine form of active community life" (Dewey, 1990, p. 14) where no gap exists between the everyday, personal experiences of the child and the subject matter of curricula (Dewey, 1990). Except for the clues provided by the choice of words, one would have difficulty attributing the following passage to Dewey, Hawkins, Duckworth, Hein, Morrison, or any member of the ESS team:

> Development does not mean just getting something out of the mind. It is development of experience and into experience that is really wanted. And this is impossible save as just that educative medium is provided which

> will enable the powers and interests that have been selected as valuable to function. They must operate, and how they operate will depend almost entirely upon the stimuli which surround them and the material upon which they exercise themselves. The problem of direction is thus the problem of selecting appropriate stimuli for instincts and impulses which it is desired to employ in the gaining of new experience. What new experiences are desirable, and thus what stimuli are needed, it is impossible to tell except as there is some comprehension of the development which is aimed at; except, in a word, as the adult knowledge is drawn upon as revealing the possible career open to the child (Dewey 1990, pp. 196-197).

Correspondence, however, breaks down with Dewey's notion of critical reflection, particularly intellectualization, and the equating of thinking with problem posing and problem solving, or a scientific habit of mind. Hawkins discusses this "serious error" in the context of the rat-in-maze experiments of laboratory psychologists. It seems that rats wandering, through a maze, not for a promised reward, but after they were well fed, would sniff about, explore, and generally make themselves at home. These same rats brought back to the hungry state and re-tested, invariably ran the maze better than control groups. Hawkins writes:

> The rat who pokes around in his world, who learns its highways and byways just because he is well-fed and curious, will have a better chance of escaping enemies than one who does not; but he does not explore well in the presence of enemies, and when he explores well it is not out of anxiety about those enemies. The map building propensities of men are vastly larger, and education confines at its peril. For the motivation of learning that is really important is the motivation intrinsic to learning itself. And the only satisfaction, the only reinforcement that counts importantly is that which accrues from discovery, from finding structure and order in our own individual and unique experience (Hawkins, 1970d, p. 62).

This is what Burner has in mind when he writes about intellectual potency, the shift from extrinsic to intrinsic motives/rewards, and conservation of memory.

Given the attention paid to children, teachers, psychology, and the nature, structure and processes of science in the development and implementation of these programs for school science, one can't help but be puzzled by the rapidity at which they ceased to be used. In a 1982 report by science educators Shymansky and Kyle, and biologist Alport, the following questions were posed:

> Whatever happened to ESS (Elementary Science Study), SCIS (Science Curriculum Improvement Study), and SAPA (Science – A Process Approach)? Why, in less than 10 years, have hands-on, activity-based programs faded almost entirely from the elementary school curriculum after so much time, effort, and money were invested in developing and introducing them? (1982, p. 14)

Those who have examined the inquiry-based science curricula of the 60s in an attempt to determine why they did not live up to expectations offer a number of probable causes. As will be shown, these run the gambit from the practical to the philosophical.

Reasons for the Demise of the NSF Funded Science Curricula

In the article titled, "Why the 'New' School Science Doesn't Sell", Butzow (1973) discusses the obstacles to implementation that he observed while working as a teacher educator in northern New England. He attributes a failure to adopt the federally funded science programs and, thus, lack of change in science education, to three factors. These are: (1) ignorance of the existence of SAPA, SCIS, and ESS or perfunctory awareness that is coupled to a belief that the programs are experimental and "too radically different from what is in current use"; (2) perceptions about the role of science in the formal education of young children; (3) and differences between "the science teaching understanding" of school policy makers and the developers of the new science programs. Butzow contends that teachers would rather have young children read about science and learn descriptive terms than do science. Moreover, his study of administrators and curriculum committees lead him to believe that few will decide in favour of non-traditional methods because such methods require school-wide or district-wide adoption and, given the hierarchical nature of programs like SCIS and SAPA, several years to phase-in. Concept-based text series somehow circumvent this problem. In addition, they provide a program for elementary school science that is considered foundational and, therefore, fundamental to secondary and post secondary science education.

It is the notion of "fundamental" that Klopfer and Champagne (1990) and Bybee and

DeBoer (1994) attempt to elucidate. To understand their interpretations, an awareness of the aims of science teaching is necessary. Bybee and DeBoer (1994, pp. 357-359) look at the standard components of school science (*i.e.* scientific knowledge, scientific methodologies, and scientific applications) and posit four basic goals for formal science education. These are personal development, social efficiency and effectiveness, the development of science, and national security (*c.f.* the four goal clusters formulated by the Project Synthesis staff as quoted in Welch *et al.*, 1981, namely: personal needs, societal issues, fundamental knowledge, and career education/peparation). The priority and emphasis of these common goals is believed to determine the structure of science curricula and the pedagogic parameters of instruction. Thus said, the curriculum reform of the sixties is considered to be a reaction by scientists and personnel of science and technology businesses and corporations to the progressive era in education; a period between 1917 and 1957 when the goals of personal development and social relevance predominated According to Welch, university and industrial scientists believed that there was a "science manpower shortage" and that "high school education [with outmoded curricula and outdated textbooks (Duschl 1990, p. 19)] was the weak link in the system" (1979, pp. 283-285). This perception is understood by Klopfer and Champagne (1990) as a being a struggle between the professionalists and the visionaries[29], by Mintzes and Wandersee (1998a) as academists versus practicalists, and by Bybee and DeBoer (1994, p. 375) as a movement away from "an intellectually weak" curricular focus "toward intellectual rigor, mastery of the structure of the discipline in a way that modeled the way scientists themselves thought and created knowledge". In other words, with scientific knowledge being the primary goal, the crucial knowledge for science teaching became the concepts and conceptual schemes that formed the structure of the discipline, and the means of attaining this fundamental knowledge was scientific inquiry, discovery and problem solving, not reading obsolete and dilute information printed in textbooks and remembering teachers' third-hand elaboration of what scientists had earlier explained.

In an effort to present scientists' current knowledge and to "restore the primacy of subject matter" to the science curriculum (Physical Science Study Committee as quoted in Easley, 1959, p. 5), the pre-college programs were to become dominated by scientists. As Duschl writes: "Individual projects were directed by prestigious scientists, coordinated by advisory boards composed of prestigious scientists, and written by scientists" (1985, p. 547). "Science for scientists" became the catch phrase (Duschl, 1988, p. 59; Duschl, 1990, p. 22), and solutions to the question "What does it take to provide an accurate picture of my discipline?" (Hurd, 1969, p. 34) established what was to be taught and how it was to be learned. This was a reform movement Smith (1966) and Gatewood (1968) describe as elitist, and that Jackson (1983, pp. 144-145) suggests placed academic excellence, quality, and achievement ahead of equity and social justice. The consequences for teachers were many.

Teachers were to work from materials that were developed to be teacher proof [30](Yager 1992), and although the programs, through the auspices of the NSF, provided numerous opportunities for in-service teacher training (Welch, 1979), support from the few curriculum specialists and science supervisors at district and state levels was minimal (Welch, 1981). As a consequence, many teachers were ill-prepared to guide students in inquiry learning (Arons, 1983; Welch, 1981). According to Arons (1983), college science preparation failed to provide school teachers with the knowledge and understanding necessary for effective use and implementation of materials. As such, they could not respond fruitfully to the observations or questions of thoughtful students (Stake and Easley, 1978 as quoted in Welch, 1981, p.61), and, when hands-on experiences were provided, the focus tended to be on observation and measuring skills rather than problem solving. Welch (1981, pp. 63-64), in fact, suggests that values associated with speculative, critical thinking were "often ignored and sometimes ridiculed" while "the careful, productive conforming aspects of schooling and socialization" were supported. Classroom based studies of this sort, prompted Jackson to write the following:

> Today's students are now being exposed to content that is more factually correct, in the sense of being closer to what leading scientists claim to know, than was true in the past; yet the new material is still being taught in

> "old" ways, with an emphasis on recitation and the memorization of facts. The notion of science as a process, a mode of inquiry, seems not to have caught on, even among those using the inquiry-oriented materials (1983, p. 151).

In their own defense, teachers pointed to a number of factors inhibiting adoption and classroom implementation of the new, federally funded curricular materials. These included inadequate preparation and support as well as managerial problems which Martin summarizes as follows:

> Often, the new programs were simply handed to teachers with instructions to replace the old programs with the new ones. Teachers were not trained in the use of the new materials, did not know the rationales for them, and were not informed of the program goals or what the new programs were supposed to accomplish. Using the new materials was expensive; teacher preparation time was extensive. Teachers were afraid of losing control of their classes by allowing children freedom to explore... (2000, p. 19).

There was also the belief, mentioned by Welch, that the materials and discovery methods "didn't work for most students" (1981, p. 61). Secondary school teachers complained that the curricula were designed for college bound students preparing for scientific careers, not those of average ability or with little interest in science (Jackson, 1983). Similarly, teachers of children in elementary schools complained that the programs "were beyond the reach of the average youngster, to say nothing of those below average" (Jackson, 1983, p. 153; see also, Arons, 1983): a difficulty which was believed to be the consequence of "a logical rather than a psychological ordering of subject matter" (Hodson, 1988, p. 19; also see Ausubel, 1965, pp. 260-261). Although Arons (1983) contends that it was equally a problem of pacing (too rapid), failure to examine underlying assertions, and teachers' lack of understanding. Whatever the case, such first-hand assessments, coupled to the unequivocal results of studies on the effectiveness of the new curricula (prior to meta-analysis techniques), led many teachers to conclude that children didn't learn as much in classrooms where student inquiry and practical (hands-on) experiences were emphasized (Kyle, Shymansky, and Alport, 1982; Shymansky *et al.*, 1982; Shymansky, 1989).

Finally, Butzow (1973) reports that teachers in his study found the new programs to be too loosely organized. He quotes one teacher who describes SAPA as confusing: it did not stress the topics of science but jumped from physics to biology. This, and similar comments, were interpreted by Butzow as being a consequence of a conflict in objectives. Where traditional, textbook-based programs envisioned science as a body of verified knowledge and focused upon preparing students for the next level in formal education, the new programs attempted to help children develop skills they could use as children. That is, "[t]hey were developed for the child as he is now, rather than as he will be later" (Butzow, 1973, p. 21). This is a conflict that is mentioned again and again by those trying to understand why reform did not go as well as planned (see Arons, 1983; Hurd, 1969; Jackson, 1983; Welch, 1981; Welch, Klopfer, Aikenhead, and Robinson, 1981;among others).

Plausible causes associated with the limited success of the NSF-sponsored programs did not end with the level of difficulty of the materials and the inadequacy of logistic support for classroom teachers. Welch (1979) mentions unforeseen problems such as integration, student unrest, declining secondary school enrollments, school reform movements, environmental concerns, inflation, and a fading public image of science. Jackson (1983, pp. 154-155) discusses in detail the "deep and fundamental uneasiness", "ambiguity and confusion", and "waffling and indecision" associated with federal tax dollars being spent on the development of pre-college curricula and the production and distribution of the curricular materials created. The repercussions that congressmen associated with what is described as an "Orwellian threat of thought-control" by means of a national uniform curriculum and Welch's unanticipated challenges will not be elaborated here. Rather, the focus will be the charge, leveled against the scientists directing the development of programs, that relevant developments in curriculum research and in the history and philosophy of science were ignored.

While the theoretical writing of Piaget, Bruner, Schwab, and Gagne provided the rationale for much of the curricular work at the elementary level during the 1950s and 1960s, Abimbola (1983), Duschl (1985; 1988; 1990), and Hodson (1985;1988) argue that epistemological issues in the philosophy of science should have guided the development of the new curricula as well. This position is summed up meticulously by Hodson (1988) who attributes the failure to improve the quality of science curricula and science instruction to teachers' inadequate views about the nature of science and to the confusion in the philosophical stance of the programs developed. He writes:

> The period of rapid change in the science curriculum, referred to earlier, was coincident with equally rapid changes in the philosophy of science, characterized by the work of Popper, Kuhn, Lakatos, Feyerabend, Laudan, Putnam, and others. In general, the former was uninformed by the latter, and the views of science methodology contained within the curriculum proposals were confused, frequently contradictory, and "based on dubious or discarded philosophies of science" (Martin, 1979). There was too much emphasis on inductive methods, a too-ready acceptance of an instrumentalist view of scientific theory, a serious underestimate of the complex relationship between observation and theory, and a neglect of the activities of the scientific community in validating and disseminating scientific knowledge. Perhaps even more damaging was the mistaken assumption that scientific knowledge is best learned through experiences based on the procedures of science. In this latter respect, the basic error was in assuming that the pedagogic content of the learning experiences is identical with the syntactical structure of the discipline being studied. Curriculum developers confused the teaching of science *as* inquiry (i.e., a curriculum emphasis on the processes of science) and the teaching of science *by* inquiry (using the processes of science to learn science). It was assumed that the attainment of certain attitudes, the fostering of interest in science, the acquisition of laboratory skills, the learning of scientific knowledge, and understanding the nature of science were all to be approached through the methodology of science, which was, in general, seen in inductive terms (1988, p. 22).

Duschl (1985) suggests that developments in the history and philosophy of science were ignored for two reasons. First, the NSF-funded projects, with the exception of Harvard Project Physics, did not include historians or philosophers on their advisory boards or writing teams. Second, the credibility of the new philosophical views among scientists was low. With respect to the latter, Mintzes and Wandersee draw upon the writing of others and speculate that "the 'empirical flavor' of psychology was more attractive to the scientists themselves than the ephemeral reflections of armchair philosophers" (1998a, p. 35). In contrast to this view, Ausubel, an educational and developmental psychologist active during the reform movement, argues that "[t]he philosophy of science should not be taught [explicitly or implicitly] to scientifically unsophisticated individuals" (1965, p. 256). The reason given centres on the knowledge and understanding that is necessary not only with respect to subject matter and the nature of a given discipline, but also with respect to the level of cognitive maturity, or Piaget's genetic epistemology. This is a detail singled out and developed by Herron (1969, p. 107) who considers the pursuit of "an adequate account" of the nature of science as being, fascinating, worthwhile and "critically necessary to science curriculum building and to the training of science teachers". Notwithstanding, this is a pursuit that he claims is fraught with uncertainty and, as a result, is much less a panacea than Pandora's Box. He writes:

> If there are, in fact, a variety of equally viable points of view corresponding to different "schools" of philosophical thought, are some of them more appropriate than others for different curricular purposes? That is, would one "model" be more appropriate to the education of the future scientist and other for the nonscience career oriented? Or can we agree upon a single particular point of view appropriate for students in all science classes? Are some points of view more appropriate to the biological science and others to physics and chemistry? With what detail do we wish to examine such materials... and how specific should we get with curricular materials? To what extent does one falsify such materials for the sake of "simplification" to increase the probability of their comprehension by those at a relatively unsophisticated level? Perhaps we would like to reconsider whether this objective is what we want to pursue or not. "After all," some will say, "we are interested in the teaching of *science* courses, not philosophy courses. Even if we were to suppose that we *could* arrive at a semblance of understanding of several complete and adequate accounts of scientific inquiry, how much time can we afford to devote to such questions when there is so little time to do what we would like to do now" (1969, p. 107).

Hodson offers an interpretation that differs subtly from those just mentioned. He uses arguments put forth by Green and Scheffler to answer two questions believed to be crucial in the design of science curricula. These questions are, can one learn what it is to be scientific without being scientific, and, can one be scientific without knowing what it is to be scientific. The conclusion reached by Hodson is that practitioners trained in science (the scientists) "need to be less knowledgeable about their discipline (in a philosophical sense) than those who teach" and are educated in science (1985, p. 28). This may give new meaning to Welch's (1979, p. 288) contention, shaped by personal experience, that the scientist-writers "were usually hesitant to accept the criticism of their 'science' from school teachers" piloting the new programs. However, it could be as Ivany suggests, that failure to include a philosophical underpinning was the mere consequence of complacency brought about by the psychological and philosophical (epistemological) uses of the word "enquiry". That is, the use of philosophical terminology, in this case "enquiry oriented", led many to assume that philosophical thought was "well represented" (Ivany, 1969, p. 114). In actual fact, it wasn't. Inquiry/enquiry in the psychological sense employed by Bruner and Gagne and Piaget was very different from its contemporary meaning in an epistemological context (Ivany, 1969; Hodson, 1985). According to Matthews (1994, p. 147), the psychologists' student-led discovery and experiment-oriented curricula produced a model of learning that was based upon a number of propositions "more characteristic of Aristotelianism" than they were of modern science. In this context, Cawthron and Rowell write:

> With hindsight the movement gradually became an intellectual fashion; an ideology as Popper defines the term. Science involves inquiry, and children were to learn this where possible by engaging in the process. Herein lay the seed of possible confusion. Educators, naturally, were virtually concerned that children should learn, influential psychologists were assuring them that a 'discovery' approach had marked advantages and, 'science is discovery.' It all seemed to fit; the logic of knowledge and the psychology of knowledge had coalesced under the mesmeric umbrella term 'discovery' and there was no very obvious reason for educators to look further than the traditional inductivist-empiricists explanation of the process (1978, pp. 37-38).

The failure to look further, to have adopted wholeheartedly "the mistaken legacy" of Aristotle, Locke, Hume, and the British empiricists, is described by Matthews (1994) as unfortunate and unnecessary. It is generally agreed that the implicit empiricist-inductivist characterization of the projects distorted scientific methodology and the nature of science, specifically, how scientific ideas are formulated, tested, and revised (Abimbola, 1983; Cleminson, 1990; Driver, 1994; Duschl, 1988, 1990; Finley, 1983; and Hodson, 1985, 1988). Rather than developing the arguments to which Hodson alludes in the critical synopsis quoted above (see page 115), the salient points from the writing of Abimbola (1983), Cleminson (1990), Driver (1994), Duschl (1988, 1990), Finley (1983), Hodson (1985, 1988, 1990), Matthews (1994), Millar (1994), Millar and Driver (1987), Robinson (1965) Stinner and Williams (2000) will be enumerated. These are:

1. observation is not a neutral or unprejudiced activity; observations are not given in nature but are selected by the scientist who is not an unbiased, impartial, or detached spectator of the material world; any statement reporting an observation carries within it theoretical ideas (all observation is theory laden; prior knowledge and belief condition observations; or, as Claxton (1993a, p. 47) claims, "perceptions do not precede our interpretations: they are our interpretations"); without knowledge, beliefs and theories (a frame of reference) one does not know what to observe (all observation is theory dependent); discovery favours the prepared mind (it is not possible to recognize a problem if an anomalous difference between what a theory predicts and what is observed fails to be perceived);
2. scientific knowledge is neither grounded in, nor the product of, sense data, sensory impressions, or sense experiences with the physical environment; scientific knowledge does not emerge from objective and detailed observation or inferences formed from first hand observations; there is no known logical procedure for formulating a general statement or principle from specific sets of discrete observations; useful and meaningful organizations of the "facts" of sense data can occur only in the context of a particular conceptual scheme; a fact can no longer be perceived as an objective statement;
3. rather than being revealed or arrived at through inductive reasoning, scientific hypotheses and theories are human constructs produced by creative acts of abstraction, imagination, and invention to explain observations and to make precise predictions;

theories are not simple guesses about nature; theories are provisional (subject to modification), they are not absolute, unalterable, fixed truths; good theories are neither validated by direct observations nor abandoned without compelling evidence; successful falsifying tests of existing theories are rare; and

4. a specifiable scientific method with generalizable intellectual skills does not exist; there is no algorithm, or set of methodological rules, for gaining (discovering) or validating (justifying) scientific knowledge; processes do not precede concepts, concepts inform and determine the processes by which knowledge is constructed and validated, as a result, methods/processes are not independent of content or context, thus, when the situation changes, the methods change; the different sciences utilize different theories, require different kinds of evidence, and employ different procedures of inquiry.

These four sets of statements are attempts to clarify the intellectual and technical means in which knowledge claims are developed and tested in science. Collectively, they bring to the fore the question posed by Bruner and reiterated above: "Is the inductive approach a better technique for teaching principles?" Philosophers of science interested in a high degree of similitude between school science and the nature of science would not hesitate in responding, "no", if the technique for teaching is free and open exploration exclusively. One wonders if the same can be said for cognitive psychologists interested in education, particularly formal education in science. On this point, Driver, a science educator and social constructivist, states:

> The more simplistic interpretations of the discovery approach in science suggest that we only need to give pupils the opportunity to explore events and phenomena at first hand and they will be able to induce the generalizations and principles themselves. The position suggested here is that children do make generalizations from their first-hand experiences, but these may not be the ones the teacher has in mind. Explanations do not spring clearly or uniquely from data. ... If we wish children to develop an understanding of the conventional concepts and principles of science, more is required than simply providing practical experiences. The theoretical models and scientific conventions will not be 'discovered' by children through their practical work. They need to be presented. Guidance is then needed to help children assimilate their practical experiences into what is

> probably a new way of thinking about them. The slogan 'I do and I understand' is commonly used in support of practical work in science teaching. We have classrooms where activity plays a central part. Pupils can spend a major portion of their time pushing trolleys up runways, gathering, cutting and sticking tangling metres of ticker tape; marbles are rattled around in trays simulating solids, liquids, and gases, batteries and bulbs are clicked in and out of specially designed circuit boards. To what end? In many classrooms, I suspect, 'I do and I am even more confused' (1994, pp. 47-48).

This is not to suggest that an inductive model of teaching has no place in formal science instruction. It is, Eggen and Kauchak (1996) argue, grounded in constructivism; the belief "that learners construct their own understanding of the world" (p. 59), and intended for use in the teaching of concepts, generalizations, principles, and academic rules irrespective of subject matter. Its effectiveness, however, is dependent upon several factors, namely: (1) the clarity of objectives (content goals and metacognitive goals); (2) the quality of illustrative examples provided ("if the example is good enough, all of the information that the student needs to understand the topic is contained in the example"); (3) the quality, pacing and number of open-ended and convergent questions that help learners in the re-construction/construction of new conceptions; and (4) a classroom environment "in which students feel free to take risks and offer their conclusions, conjectures, and evidence without fear of criticism or embarrassment".

The model presented by Eggen and Kauchak is composed of five steps that have been labeled as follows: lesson introduction, the open-ended phase, the convergent phase, closure, and application. There is no doubt given the discussion accompanying each step that the inductive model subsumes guided discovery, many forms of guided inquiry, the SCIS learning cycle, and Hawkins' interpretation of effective teaching in the ESS program. Thus, Hodson's (1985) declaration of the absurdity of the suggestion that all science content must be learned through the methods and procedures of science. This is not to say that epistemologically valid methods and procedures should not be reflected in the practical work of school science, only that it may be necessary to separate the epistemological and the psychological "if satisfactory learning experiences are to be provided" (Hodson, 1985, p. 41).

IMPLICATIONS FOR CURRICULUM DEVELOPMENT

For developers of science curricula, the task would seem to be to synthesize what has been presented and then, in light of this information, to fabricate series of lessons that teach science (scientific knowledge) and teach about science (the nature of science) in a manner that is philosophically, psychologically, and pedagogically valid. Given the documents[31] currently driving curriculum reform in North American science education and their emphasis on scientific inquiry, active learning, and inquiry-based programs, such a synthesis is not only pertinent but necessary. The reasons for this opinion are shaped, in part, by the views of Derek Hodson and Arnold Arons.

Hodson (1985, pp. 39-40) expands the meanings assigned by Rutherford (1964) to teaching science as inquiry (see above, pages 54-55). While maintaining inquiry as technique (Rutherford's "using the method of scientific inquiry to learn some science"), he teases apart inquiry as content (Rutherford's "inquiry as it appears in the scientific enterprise") and distinguishes between teaching science as (1) a method of acquiring knowledge, (2) a set of inquiry skills, and (3) a general and generalizable method of inquiry (*c.f.* Welch, Klopfer, Aikenhead, and Robinson, 1981). In the first instance, the curriculum emphasis is epistemological issues (*e.g.* the status of scientific observations, the nature of scientific theories, and the methods of scientific inquiry). In the second, the acquisition and use of specific skills (*e.g.* Gagne's primary process skills). In the third, the acquisition and use of general strategic skills (*e.g.*: problem-solving, logical reasoning and decision making). While all have a legitimate place in well-grounded science curricula, it is, as Hodson argued immediately above, naïve to believe that each can be achieved through learning experiences that attempt to model scientific research. Hodson, in fact, provides the following list of general outcomes and suggests that different kinds of experiences may be necessary for attaining each specific one:

a. acquisition of factual and theoretical knowledge;
b. critical scrutiny of evidence and arguments for and against particular theories;
c. practice in using theories for explaining phenomena;
d. using theory for prediction;
e. acquisition of laboratory skills and techniques;
f. testing predictions and other consequences of particular theories;
g. designing experiments to test hypotheses or to illustrate theories;
h. hypothesis generation;
i. testing hypotheses by logical criticism (internal consistency, compatibility with other existing theory);
j. testing hypotheses by experiment;
k. appreciation of socio-economic and historical issues concerning science and its applications; and
l. appreciation of the nature of science, scientific methods and scientific practice (1988, p.34).

This suggestion, when juxtaposed with the *Common Framework of Science Learning Outcomes K to 12* (Council of Ministers of Education, Canada, 1997) and *Kindergarten to Grade 4 Science: Manitoba Curriculum Framework of Outcomes* (Manitoba Education and Training, 1999) is startling; not for reasons of congruence, but in making conspicuous the failing to communicate the complexity of scientific inquiry. In the Canadian document, written as a framework for curriculum developers, students are to be engaged in (1) active inquiry, (2) problem solving, and (3) decision making. It is suggested that although the particular contexts may vary, the overall scope and focus will normally include these three "broad areas of emphasis". The science inquiry emphasis is one "in which students address questions about the nature of things" (Council of Ministers of Education, Canada, 1997, p. 8). Solutions to these questions are to emerge from either "broad explorations" and/or "focussed investigations". This is interpreted by the Manitoba development team as being a cycle of problem posing and problem solving as the following passage illustrates:

> Scientific inquiry is a way of learning about the universe. It involves posing questions and searching for explanations of phenomena. Although no single "scientific method" exists, students require certain skills to participate in science-related experiences.
> Skills such as questioning, observing, inferring, predicting, measuring, hypothesizing, classifying, designing experiments, collecting, analysing, and interpreting data are fundamental to scientific inquiry; as are attitudes such as curiosity, skepticism, and creativity. These skills are often

> represented as a cycle. This cycle involves posing questions, generating possible explanations, and collecting and analysing evidence to determine which of these explanations is most useful and accurate in accounting for the phenomena under investigation. New questions may arise to re-ignite the cycle (Manitoba Education and Training, 1999, p. 2.10).

Providing children with models, however rudimentary, or an adequate understanding of the preconceptions or theoretical framework by which successful conjecture is possible is not mentioned. Hodson makes clear that speculation within the paradigm and hypothesizing within the paradigm is exploration, and that this kind of exploring, which helps to develop understanding, can lead to experimental testing: "testing of the adequacy of a particular theoretical proposition for explanation and prediction" (Hodson, 1988, p. 29). It makes no difference whether the problems are empirical or conceptual (Finley and Pocovi, 2000).

Unlike the Canadian counterpart with skill, attitude, and knowledge outcomes, the American curriculum document, *National Science Education Standards* (NRC, 1996), has been developed with standards for science teaching, professional development, assessment, science content, science programs, and science education systems. Interspersed through the presentation are generalizations, again so ill-defined as to become indistinguishable from those previously determined to be philosophically unsound, for example:

> Inquiry into authentic questions generated from student experiences is the central strategy for teaching science (Chapter 3, Science Teaching Standards, p. 31);
>
> Science as inquiry is basic to science education and a controlling principle in the ultimate organization and selection of students' activities (Chapter 6, Science Content Standards, p. 105); and
>
> Full inquiry involves asking a simple question, completing an investigation, answering the question, and presenting the results to others (Chapter 6, Content Standards: K-4, p. 122).

The authors, however, are neither oblivious nor uninformed of the problems of induction, and they do not insist on inquiry as the sole approach to science teaching and learning. Their understanding is expressed in the following two passages:

> The *Standards* call for more than "science as process," in which students learn such skills as observing, inferring, and experimenting. Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others... The importance of inquiry does not imply that all teachers should pursue a single approach to science teaching. Just as inquiry has many different facets, so teachers need to use many different strategies to develop the understandings and abilities described in the *Standards* (Overview, p. 2);
>
> Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations... Although the standards emphasize inquiry, this should not be interpreted as recommending a single approach to science teaching. Teachers should use different strategies to develop the knowledge, understandings, and abilities described in the content standards. Conducting hands-on science activities does not guarantee inquiry, nor is reading about science incompatible with inquiry. Attaining the understandings and abilities described in Chapter 6 cannot be achieved by any single strategy or learning experience (Chapter 2, Principles and Definitions, pp. 23-24);

Unfortunately, as in science, one must first know what to look for in order to understand what is being perceived and, in this particular case, being said. Testing explanations against "current scientific knowledge" and reviewing "what is already known" in light of experimental evidence, does not inform the curriculum developer or teacher or reader, with precision, as to the source of the knowledge against which claims will be made and conclusions drawn. Is it to be the knowledge of the community of scientists or the knowledge sifted through the authors of print-based resources and texts or the knowledge of individual members of the classroom community or the knowledge of any number and combination of conceivable candidates? The answer without doubt is tied to one's goals for formal education in science.

In spite of all that has been written, Arnold Arons (1983, p. 118) suggests that "a significant number of excellent curricula" were developed with the support of the National Science Foundation, and, within this significant number, he designates SCIS and ESS as being among the best. Not only does he describe these curriculum materials as "interesting, imaginative, and educationally sound", they are also considered to be excellent because

> children start from scratch, with no presuppositions concerning prior "knowledge" of technical terms. Ideas come first and names afterward. Concepts are synthesized out of observational experience rather than received through didactic presentation. Reasoning starts at concrete levels and, provided it is under the guidance of a competent teacher, gradually proceeds toward the abstract (p. 118).

This is Arons interpretation of Hawkins' O Phase using the ESS materials and Karplus' exploration phase of the learning cycle in the SCIS materials.

"Failure" of the curriculum development efforts, as a consequence, is not attributed to deficiencies in the quality or character of the materials. Arons, in fact, quips, "[c]urricular materials, however skillful and imaginative, cannot 'teach themselves'." It is for this reason, he suggests that curriculum reform with its promise of a new generation of better and more effective resources for teaching and learning is "a fallacious and forlorn hope." Shymansky (1989), a defender of ESS, SCIS, and SAPA, would perhaps concur. Based upon significant gains in student performance and attitudes shown by meta-analysis of sixty studies, he advises curriculum developers to use these NSF materials as a foundation on which to construct any new elementary science program.

One conclusion to draw from Arons' and Shymansky's writing is that the criticisms of the curriculum products developed with the NSF's monetary support were too far reaching. By being all-inclusive, distinctions were not made between programs grounded in outdated or contemporary notions of sound instructional practices with respect to the psychology of learning and the philosophy of science. The descriptions provided of SAPA, SCIS, and ESS were included so as to make this claim obvious, particularly with respect to SCIS and ESS as envisioned by Hawkins. It's difficult to name more thoughtful resources for early years teachers who seek subject knowledge as well as pedagogic and curriculum knowledge.

[1] Abductive reasoning involves the generation of hypotheses that tentatively explain puzzling encounters. According to Siegel and Carey (1989, p. 25), Peirce believed "that abduction was the only form of logic capable of starting new ideas." Possible consequences of these hypotheses were tested (in thought) using deductive reasoning and (in action) against real world phenomena and experiences using induction.

[2] "Students, perforce, have a limited exposure to the materials they are to learn. How can this exposure be made to count in their thinking for the rest of their lives? The dominant view among men who have been engaged in preparing and teaching new curricula is that the answer to this question lies in giving students an understanding of the fundamental structure of whatever subjects we choose to teach" (1963, p. 11).

[3] "...the basic ideas that lie at the heart of all science and mathematics and the basic themes that give form to life and literature are as simple as they are powerful. To be in command of these basic ideas, to use them effectively, requires a continual deepening of one's understanding of them that comes from learning to use them in progressively more complex forms... A curriculum as it develops should revisit these basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them" (1963, pp. 12-13).

[4] "...any subject can be taught effectively in some intellectually honest form to any child at any stage of development" (1963, p. 33).

[5] I refer here to the work of the Geneva school in developmental psychology, specifically Jean Piaget and Barbel Inhelder.

[6] Similar to Kuhn's scientists working between paradigms who invent new ways of giving order to data.

[7] Schwab is referring to the level of prescription in laboratory work. He describes three levels of openness and permissiveness, these are: (1) the laboratory manual states the problem to be investigated and describes the methods that one should use to discover unknown (as yet untaught) relationships; (2) problems are posed and the methodologies and answer solutions are not described, they are open; and (3) problems as well as methodologies and answer/solutions are open.

[8] "Climactic narrative begins with description of phenomena which symbolize the field to be treated... With such a starting point, a problem is formulated and the narrative moves thereafter from one experiment, its results and interpretation, to another until it reaches its intended stopping place, its climax theory" (Schwab, 1960, p. 10).

[9] "Multilinear exposition is one which includes description of alternatives, difficulties, and doubts attendant on enquiry. Some of the alternatives taken seriously at a given time are examined in the light of their various supporting evidences. There is emphasis on the uncertainties and losses involved in choosing one over other alternatives" (Schwab, 1960, p. 10).

[10] "A rhetoric of conclusions, then, is a structure of discourse which persuades men to accept the tentative as certain, the doubtful as the undoubted, by making no mention of reasons or evidence for what it asserts... the current and temporary constructions of scientific knowledge are conveyed as empirical, literal, and irrevocable truths" (Schwab, 1962a, p. 24).

[11] These are PSSC - High School Physics; Chemical Bond Approach; Biological Sciences Curriculum Study-High School Biology: Blue, Green, and Yellow versions; Chemical Education Materials Study; BSCS-Interaction of Experiments and Ideas; PSSC-Advanced Topics; Earth Science Curriculum; Introductory Physical Science; Quantitative Physical Science; Time, Space and Matter; Project Physics (Klopfer and Champagne, 1990, p. 140).

[12] These are Elementary School Science Project, Grades 2-5; Elementary Science Study, Grades K-8; Minnesota School Mathematics and Science Teaching Project, Grades K-3; Science Concept Development in the Early School through Inquiry Training, Grades 1-8; Science Curriculum Improvement Study, Grades

K-6; Elementary School Science Project, Grades 1-2; Science: A Process Approach, Grades K-6; Quantitative Approach to Elementary School Science, Grades 3-6; and Individualized Science, Grades K-6 (Klopfer and Champagne, 1990, p. 141).

[13] Gagne's research in psychology is based upon a hierarchy of learning capabilities, and he developed a theoretical model of a simple-to-complex hierarchy of types of learning. SAPA is build upon this theory, and the simple to complex ordering of subskills and processes is "based on what seemed logically correct in science and psychologically accurate for most children" (Butts 1973, p. 183). The literature accompanying the SAPA program states: "Gagne has shown that if a learner attains behaviors subordinate to a higher behavior, there is a high probability that he can attain that higher behavior. On the other hand, if he has not attained the subordinate behavior, there is near zero probability that he can attain the higher behavior" (AAAS/Xerox 1967a, p. 10). Each SAPA activity is designed specifically to help children acquire the subskill or skill necessary for the next step in the learning process. The SAPA hierarchy is established by "identifying the most complex behavior, *i.e.*, the terminal behavior, that a child is expected to develop in each of the processes. Then this terminal behavior is analyzed to determine what subordinate behaviors the child should have acquired before he can be expected to achieve the terminal behavior. Each of these subordinate behaviors is analyzed in turn to determine what prior behaviors are required before the child can be expected to achieve each of them. This procedure is continued until the simplest behaviors are reached. The hierarchy chart for each process lists all of the behaviors that have been identified in this way and indicates this intradependence" (AAAS/Xerox, 1967a, p. 7).

[14] Modules a and i are Classifying 4 (*Observing Living and Nonliving Things*) and Classifying 5 (*Variation in Objects of the Same Kind*).

[15] Modules b, c, q, s, and t are Using Space/Time Relationships 7 ((*Symmetry*), Using Space/Time Relationships 8 (*The Shapes of Animals*), Using Space/Time Relationships 9 (*Shadows*), Using Space/Time Relationships 10 (*Recognizing and Using Angles, Direction, and Distance*), and Using Space/Time Relationships 11 (*Time Intervals*).

[16] Modules d, j, l, n, u, and z are Measuring 2 (*Linear Measurement*), Measuring 3 (*Comparing Volumes*), Measuring 4 (*Linear Measurements Using Metric Units*), Measuring 5 (*Making Comparisons Using a Balance*), Measuring 6 (*Ordering Plane Figures by Area*), and Measuring 7 (*Seeds and Seed Germination*).

[17] Modules f, k, and r are Using Numbers 5 (*Numbers and the Number Line*), Using Numbers 6 (*Numbers 0 Through 99*), and Using Numbers 7 (*Addition of Positive Numbers*).

[18] Modules e, g, m, o, and v are Observing 9 (*Observation, Using Several of the Senses*), Observing 10 (*Observing the Weather*), Observing 11 (*Observing Some Properties of Magnets*), Observing 12 (*Observing Color and Color Changes in Plants*), and Observing 13 (*Observing Mold Gardens*).

[19] Modules h, p, w, x, and y are Communicating 1 (*Identifying an Object*), Communicating 2 (*Introduction to Graphing*), Communicating 3 (*Describing Physical Changes*), Communicating 4 (*Observing Collisions*), and Communicating 5 (*Describing Changes in Plants*).

[20] These experiences involve stories, field trips, building a simple thermometer and using it to measure temperature, the construction and care of mold gardens, games that involve the identification of materials in "mystery bags," developing a classification key, the establishment and care of living and nonliving materials in aquaria, using a gnomon, observing falling objects, constructing a bar graph and interpolating on the graphed data, and the like.

[21] The generalizing experiences are contexts that enable, and invite, children to use the skills they are developing to complete a task. These may be as basic as following the directions on a map to find a "hidden treasure" and playing a game of twenty questions or as complex as playing on a merry-go-round to experience, and then discuss, how position with respect to the axis of rotation affects the start-up speed and how movement from the outer edge to the center during rotation affects the speed at which they revolve

around the axis.

[22] The SCIS team of developers call concepts invented by the teacher "conceptual inventions" because each concept "was once invented by a scientist" (Karplus and Thier 1967, p. 84). A conceptual invention is defined as "a new idea for interpreting experience, an idea which resulted from an inductive mental leap" (Karplus and Thier 1967, p. 40).

[23] SCIS units are divided into several parts, each part is divided into chapters, and each chapter is divided into activities.

[24] The Educational Development Center incorporates the Institute for Educational Innovation and Educational Services Incorporated and began as the parent body of the Physical Science Study Committee (PSSC high school physics) established by Jerrold Zacharias, a physicist at MIT (Rogers and Voelker 1970, p. 36; Matthews 1994, p. 16).

[25] In most cases, the recommended materials are inexpensive and common. This is to ensure that all children are actively involved, and that the equipment and supplies are "not imposingly scientific" but resemble materials assessable to children outside of school (Blough and Schwartz 1974, p. 50). It is believed that familiar materials will predispose children "to relate the subject matter of the unit to their everyday experience" (ESS 1970a, p. 8). Where specialized or hard to find materials and equipment are necessary to teach a unit's activities, they are sold in kit form as an integral part of the unit.

[26] Piltz and Sund (1968, p. 91) report that no group prior to the PSSC had ever received as much federal money to produce materials for school use (1968, p. 91).

[27] Gagne (1963, p. 27) states, "Fundamentally, the purpose of a curriculum is to organize the educational situation in such a way that students, who are at one stage, or age, incapable of exhibiting certain kinds of behavior relevant to science, become capable of exhibiting certain kinds of behavior."

[28] Bruner's cycle of learning is described in the June 17, 1961 issue of Saturday Review where he writes, "...it is essential that, before being exposed to a wide range of material on a topic, the child first have a general idea of how and where things fit. It is often the case that the development of the general idea comes from the first round of experience with concrete embodiments of ideas that are close to the child's life. The cycle of learning begins, then, with particulars and immediately moves toward abstraction. It comes to a temporary goal when the abstraction can be used in grasping new particulars in the deeper way that abstraction permits (reproduced in Bruner, 1962, p. 123).

[29] Klopfer and Champagne (1990, pp. 134-135) draw the following distinction: "For the professionalist, the main purpose of school science instruction is to provide the best possible preparation for further science study for those students who will pursue careers in the natural sciences, applied science or technology." "For the visionary, the main purpose of school science instruction is also to establish a firm preparatory foundation, but he thinks of the students' preparation not only for careers, but for life ...the visionary focuses on the development of students' functional understanding of those concepts and principles of the biological and physical sciences which will help people lead safe, sane, and more satisfying lives."

[30] Is it possible for curriculum materials to be designed as teacher proof as Yager claims? Arons (1983) suggests not. He writes: "It is unlikely that any curricular materials, however high their potential for cultivating thinking, reasoning, learning, and understanding, will ever be "teacher-proof." A teacher can always negate the intent of the materials by attitude, invidious comment, and, most significantly, by what he or she chooses to test for."

[31] These documents are the following: *Common Framework of Science Learning Outcomes K to 12* (Council of Ministers of Education, Canada, 1997), *Benchmarks for Scientific Literacy* (American Association for the Advancement of Science, 1993) and *National Science Education Standards* (National Research Council, US, 1996).

CHAPTER FOUR
RESEARCH DESIGN, METHOD, AND PROCEDURES

COMMENTS ON RESEARCH DESIGN

In the most recent edition of *Research Methods: Learning to Become a Critical Research Consumer*, Martella, Nelson, and Marchand-Martella (1999) play down the debate between quantitative *vs*. qualitative methodologies by making clear that each is focused upon answering a particular kind of research question. They maintain that it is not a matter of thinking one methodology is better than the other, but determining which is most appropriate for the study envisioned and the question(s) posed.

Quantitative research is generally concerned with the investigation of the impact of independent variables on dependent variables. The independent variable is often referred to as the treatment. It is manipulated, extraneous variables are controlled, and the response of, or change in, the dependent variable is measured and compared to a control group. The basic assumption is that the participants of the experimental and control groups are equivalent prior to the introduction of the independent variable, and that any differences observed at the end of the study are a consequence of the independent variable. Attributing differences in performance to the experimental treatment (not sampling and/or measurement errors) is determined by means of statistical significance testing.

Qualitative research has been defined by Strauss and Cobrin as "any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification" (1990, p. 17). Researchers using qualitative methods are not concerned with a few carefully, but narrowly defined variables and statistically significant effects that culminate in linear, cause-effect relationships. Their concern is with meaning: understanding the context in which behaviour occurs, the big messy picture of real world situations and, thus, the complex interdependencies of multiple variables over a period of time (Bogdan and Biklen, 1992; Guba and Lincoln, 1981; Martella *et al.*, 1999). In qualitative research, the researcher is the key data collection instrument, and data are detailed, thick descriptions, collected through fieldwork where the researcher "joins the subjects' world" (Bogdan and Biklin, 1992, p. 79). Fieldwork data are the observations, interviews, transcripts, historical records, and artifacts from which explanations are induced (*i.e.* grounded theory: theory derived from real-world data and existing theories on children in social interaction, not naïve empiricism). While the accuracy of a narrative assessment report is difficult to obtain, validity and reliability of the researcher's interpretations are judged by several criteria. These are: "completeness of information; adequacy of interpretation; determination of inconsistencies in data; adequacy of metaphors, pictures or diagrams; collaboration with participants; and multiple methods to gather data" (Franklin and Jordan, 1995, p. 291).

The questions this study attempted to answer such as, "What are the instructional variables/design tools that account for student performance?" and "How do instructional strategies affect the process and advancement of learning?", could best be answered through qualitative methods. Thus, an interpretive approach, where the researcher becomes part of the world studied, was the methodology utilized..

COMMENTS ON PARTICIPANT OBSERVATION

Studies in qualitative research are generally case studies, multisite studies, or multisubject studies. Bogden and Biklen (1992, p. 62 and 69) advise nascent researchers to choose a case study as a project due to the fact that multiple site and multiple subject approaches are "difficult to accomplish for a first undertaking." A case study involves the examination of one setting, one particular event, a single subject, or a single depository of documents and, as a consequence, can be referred to as an historical organizational case study, observational case study, life history, or document analysis.

Observational case studies are of three kinds, namely: participant observation; nonparticipant observation, and simulation. According to Guba and Lincoln, participant observation is a form of inquiry in which the inquirer plays two roles. The first is the role of an observer where the researcher "is responsible to persons outside the milieu being observed"; the second is as a genuine participant where the researcher is a member of the group, interacts with the participants, and has a stake in the group's activity and its outcomes (1981, pp. 189-190). The participant-as-observer approach, where the participants are informed of the participant observer's role and intentions, is the approach that was adopted for the study. There was no need to create or re-create a situation, as a simulation makes possible, since this was not an example of a case where the ability to collect information was in any way compromised. Nonparticipant approaches attempt to lower observer effects by unobtrusive observation. Thus, nonparticipant researchers choose not to manipulate what occurs in the natural setting. The study incorporated a unique approach to curriculum design and very specific strategies in its implementation (the "event", to use Eisner's terminology). It was essential that the investigator be informed of the understanding being developed over time (the effect of the event on experience) (Eisner, 1991, p. 183). Nonparticipant approaches to data collection would not have allowed the manipulation and interaction necessary for determining the depth and breadth of understanding and, thus, the significance of the event for the participants.

Comments on Data Collection

Validity in qualitative research refers to the "truthfulness" of the inferences and conclusions drawn from research findings. According to Martella and his colleagues (1999, pp. 270-273), qualitative researchers must be aware of descriptive, interpretive, theoretical, and evaluative validity. The first two refer to the accuracy with which data are described and interpreted. Theoretical validity is concerned with the truthfulness of the explanation that is constructed from descriptions and their interpretation. Evaluative validity is the ability to appraise a situation and to make right and wrong statements that are perceived as valid by the researcher's "public".

To enhance the validity of research findings obtained using qualitative methodologies, it is suggested that multiple sources of data be incorporated into all research designs (Graue and Walsh, 1998; Guba and Lincoln, 1981; Mathison, 1988; Martella *et al.*, 1999). The use of data from different sources or data developed using different methodologies is referred to as triangulation. The technique, when two or more processes with different assumptions and fundamental premises are used to construct propositions, is believed to make data findings credible.

Four types of triangulation are consistently mentioned (Guba and Lincoln, 1981; Mathison, 1988; Martella *et al.*, 1999). These are data triangulation, investigator/analyst triangulation, theory/perspective triangulation, and methodological triangulation. Mathison (1988) dismisses theory triangulation from her discussion because the writing of Denzin suggests that researchers committed to a given theoretical stance will not look at the research data from a different theoretical perspective. Martella, Nelson, and Marchand-Martella (1999), however, suggest that it is not unusual in some areas, like problem solving with behavioural and cognitive perspectives, for researchers to make use of this form of triangulation.

Data triangulation can be attained by including more than one individual/participant as a source of data or by examining a setting, event, or individual over time and in a variety of conditions. If more than one investigator is collecting data, or the study uses several field workers or research assistants to assess existing data and the interpretations are compared, investigator/analyst triangulation is achieved. Methodological, between methods, triangulation involves comparing the data from two or more methodologies. The methods can be qualitative or a mixture of both qualitative and quantitative. Mathison argues that the goal of triangulation is not "convergence upon the truth:" convergence requires as much explanation as inconsistent and contradictory data which are more likely to occur (1988, pp. 14-15). Rather it is to end up with information with which the researcher can construct plausible explanations for the phenomena studied.

The study was designed with a classroom of young children in mind, one investigator, and the use of several methodologies including descriptive field notes with observer comments, pre-instructional and post-instructional interviews, informal conversations with the classroom teacher, and written and pictorial artifacts. It is believed that the accumulated data provide the evidence necessary for the construction of valid propositions by means of inductive analysis.

Finding the Appropriate Research Setting

The proposed study was designed with eight criteria for selecting the site. These are, in no particular order: (1) a school within fifty kilometers of central Winnipeg; and a school with (2) a total enrollment, Nursery/Kindergarten through Grade 6, of two hundred or less; (3) operative windows and a green space appropriate for outdoor education and life science activities; (4) class sizes below 25; (5) several multi-age classrooms at the early years level; (6) teachers at the early years level who worked collaboratively to plan curricula; (7) one, perhaps two, early years teacher interested in children's learning in science; and (8) an administrator as interested and supportive of the proposed study as the classroom teacher(s).

The process of finding a school meeting the eight criteria began with the attainment of computer printouts of the private and public schools in the province of Manitoba. These lists included the school name, school division, grade levels, total enrollment, enrollment by grade, phone number, principal, address and postal code. All schools meeting criteria 1, 2, and 4 were short listed. This eliminated all but twenty-six schools in fourteen school divisions. The next step was to identify which of the twenty-six gave children access to natural light during class time and to a green space during recess. This was achieved by driving from school site to school site and placing phone calls to the principals of those considered acceptable. The phone conversations focused upon the remaining four criteria (5 through 8).

The first principal to be contacted, a teaching principal in the McPhee-Lewis School Division, suggested that a meeting be scheduled with the teaching staff to introduce the study and answer potential questions. It was after this meeting in mid-April that arrangements were made with Suzanne, one of two Grade 4-5-6 teachers, to pilot a science unit on populations, communities, and ecosystems for May and June. At the end of this collaboration, two early years teachers (Grades 1-2-3), Cecile and Lauren, whom I assisted when invitations were extended, offered their classrooms as sites for the study. With this overture, I was also informed that the Grade 3 science curriculum in the 1991 guide would be the content they would need to teach.

The School and Staff

The school in which the study was conducted is located in what was once a small farm community in south-eastern Manitoba. Today, as a consequence of several housing developments, there has been a shift from a rural to a suburban population. This has seen the school enrollment climb from 31 children during the 1986-1987 school year to 153 when the pilot study was carried out. The projected enrollment for late August was 185.

The school has a staff of twelve which includes the secretary and two custodians. The teaching staff of nine can be broken down as follows: one Kindergarten/music teacher with a 0.64 appointment; four early years teachers (two with full-time positions, one with a 0.5 appointment, and one with a 0.5 teaching appointment and a 0.5 reading recovery appointment); two middle years teachers with full-time appointments, one teaching principal, and one upper middle years teacher with a full time appointment that is divided between the classroom and the gym as the physical education instructor. There are, as a result, one morning Kindergarten class, three multi-age (Grades 1-2-3) early years classes, two multi-age (Grades 4-5-6) middle years classes, and a multi-age (Grades 7-8) upper middle years class ("early years", "middle years", and "upper middle years" are the school staff's descriptors).

The presumption made with the selection of this school as the setting for the proposed research was that it met the requirement for maximum variation sampling. This is the qualitative sampling method that does not look for deviant, typical or critical cases, but hopes for a heterogeneous sample with a great deal of participant variation (see Martella *et al.*, 1999, pp. 267-270).

Selecting The In-school Setting

Midway through the summer holiday, I met with Lauren at her request. She had been thinking about my study, and was interested in having children for whom she was responsible selected as the participants. She suggested that I design the curriculum for the five, six, seven, and eight year olds in all three early years classrooms, and that she and Cecile and I[1] meet each week to discuss upcoming lessons and activities. I wasn't immediately enthusiastic about these ideas, since my interest and focus were the thinking that the envisioned and enacted curriculum would enable children to do, not the thinking of teachers. Moreover, I had, at the outset, promised to provide the necessary materials and resources. I hadn't envisioned another approach than the one that had been successfully used the previous spring with Suzanne in the two Grades 4-5-6 classes. In this instance, the scope of the curriculum was determined by the objectives laid out in the Manitoba science curriculum guide for Grade 5. The sequence of lessons and activities, and the specific approaches for helping students attain the predetermined objectives were planned and carefully scripted by me, often the evening after the completion of a science session. Suzanne was faxed the content of each succeeding lesson and asked to follow the plans, written as a narrative in a conversational voice that invited and built upon the ideas, conceptions, and questions expressed in previous lessons by the students. When deviating, she was asked to respect the view of science and the sociocognitive participation that the curriculum was designed to enhance. I realized, with Lauren's suggestion, that having more than a single classroom teacher involved, although interesting, would most likely consume more of my time and energy and resources.

There was also the risk that the study would become altogether different from the one I envisioned. Making my apprehensions explicit, our ensuing conversation ended in compromise.

In this sixty minute meeting, my role went from participant observer to investigator-teacher. Although little changed with respect to the proposed study and its design, with hindsight, it would have been advantageous to video tape the lessons, for which I would later write copious albeit incomplete field notes, if only to have verbatim transcripts of the dialogues that became such an interesting part of the oral discourse provided for and encouraged. Regardless, control of the envisioned and enacted curricula were now in my hands. Variables associated with incomplete curricular knowledge, content knowledge, and/or pedagogical content knowledge would be less likely to influence the outcome.

THE CHILDREN

Twenty names, for eight girls and twelve boys, had been typed into Lauren's class enrollment list when I received a copy in late August. The names of seven children, three boys and four girls, were entered under the heading Grade 1. Of these seven, five began the school year as six year olds, and two, a girl and a boy, would not become six until the 3rd and 13th of December, respectively (mean age = 74.6 months or 6.2 years). The seven children listed for Grade 2 included two girls and five boys. Of these, two were eight years old when the school year began, three were seven, and two would not celebrate their seventh birthdays until the 13th and 29th of October (mean age = 90.6 months or 7.6 years). The names of four boys and two girls appeared under the heading Grade 3. Of these six, one girl and two boys began the school year at eight years of age, one boy would celebrate his eighth birthday on September 27th, and the youngest girl and boy would become eight on the 24th of December (mean age = 97 months or 8.1 years).

As a consequence of being in Lauren's class, all twenty children were exposed to and participated in the lessons of the science curriculum designed for the study. Three of the twenty children, however, were not part of the study itself. That is, they were not interviewed and their paper and pencil work was not photocopied for interpretation and analysis. In two cases, the letter requesting consent to use the data collected from the child was not returned. In the third case, the child was withdrawn from the school and enrolled at another within the division. For these reasons, the conclusions drawn are those made possible by eight girls: four in Grade 1 (Roslynn, Debbie, Anne, and Cindy) and two in each of Grade 2 (Reena and Sara) and Grade 3 (Annie and Cathy); and nine boys: three in each of Grade 1 (Willie, Danny, and John), Grade 2 (Robert, Scott, and Ken), and Grade 3 (Marc, Michael and Patrick).

THE PRE-INSTRUCTIONAL PHASE (Preplanning for the Biology Unit)

When Lauren spoke with Cecile after she and I met in early August, it was decided that they would begin the school year with the life cycles unit in the Grade 3 science curriculum guide. With this information, I began collecting resources that could be useful in planning and designing lessons, and looking for materials that might enhance children's understanding of the unit's concepts and learning objectives (see Appendix B). This included, but was not restricted to, the relevant curriculum documents developed for the ESS[2], SCIS[3], and SAPA[4] programs, selections from children's literature and trade books, commercial video recordings, living and preserved organisms, CD ROMs, current news items, three dimensional models, and two dimensional illustrations.

Pre-interview and pre-instruction planning resulted in a provisional outline that focused on the concepts emphasized in the curriculum guide. These were the life cycles of animals, metamorphosis, complete (4-stage) metamorphosis, incomplete (3-stage) metamorphosis, classification based upon life cycle, animal behaviour, instinctual behaviour, and respect (human actions that allow for the continuity of the life cycles of other organisms). It seemed prudent to begin by drawing upon the children's knowledge of the life cycle of humans. This would lead nicely into the life cycles of other phyla and classes of animals that hatch or are born resembling their adult parents anatomically, and grow, perhaps with a change in proportion, through time. From a discussion of these animals, a majority of which are classified as mammals, birds, fish, and reptiles, animals hatched or born with little resemblance to the adult parent, that change in form and structure through time, would be introduced. This includes the amphibians (frogs, toads, and salamanders) and the insects that undergo complete metamorphosis with egg, larva, pupa, and adult stages. The final lessons would be reserved for those insects that are born as immature and small scale versions of the adult parent. They go through what is referred to as incomplete metamorphosis with egg, nymph, and adult stages. In all cases local animals that children could possibly have observed in or around their neighborhoods were to be used as examples.

Plans also included the in-school culturing and care of mealworms, crickets, ladybugs, the pupa state of butterflies, and a pond water aquarium stocked with snails and fish. These organisms would not only offer daily opportunities for first hand observations of stages in the life cycles of several animals, but any investigation or scientific inquiry would very likely originate with them or the habitats in which they were maintained. The presumption made was that these living creatures would be the context through which many of the objectives would be achieved using the LEP Model and the teaching/learning strategies known to enhance understanding which the Model supports (see references in Chapter 2 to Glen and Duit (1995); Hewson, Beeth, and Thorley (1998); Hodson (1988, 1990, 1999); Lerher and his colleagues (2000); and Metz 1995, 1997, 1998, 2000). The goal being, as Duschl and Gitomer make clear, to begin to help "seeing as" learners become "seeing that" observers (1991).

Owing to the fact that the pre-instruction interviews were to be conducted before any science teaching got underway, the first task was to re-acquaint myself with studies on young children's intuitive ideas about the concepts of life, animal and animal classification, growth, and life cycles (*i.e.*: Brumby, 1982; Driver, Squires, Rushworth, and Wood-Robinson, 1994c; Lucus, Linke, and Sedgwick, 1979; Ochiai, 1989; Richards, 1989; and Stepans, 1985 for life; Bell, 1981 and; Trowbridge and Mintzes, 1985 and 1988 for animal and animal classification; Rosengren, Gelman, Kalish, and McCormick, 1991; and Russell and Watt, 1990 for growth, and Shepardson, 1996 for life cycles). I also re-read the studies of Inagaki (1989, 1990a, 1990b) and those on which she and Hatano collaborated (Inagaki and Hatano, 1991; Hatano and Inagaki, 1992). I found intriguing their idea that constrained personification in biology could be innate or an early cognitive constraint. Moreover, like the SPACE Project that operated out of the University of Liverpool, England in the 1980s and 1990s, the character of the questions asked had features I hoped to reproduce. For example, when investigating the effects of raising pet goldfish on the biological knowledge of children attending kindergarten (mean age, 70.9 months), two of the more than thirty questions posed were the following: "Someone put ice cubes into the goldfish bowl on a hot summer day. Is this good for the goldfish, or not?" and "Suppose someone is given a baby X and wants to keep it forever in the same size because it's so small and cute. Can he or she do that?" (Inagaki, 1990b, p. 122).

The pre-instruction interviews for the life cycles unit were scheduled for the second week of school. Each of the seventeen children participating in the study met with me for approximately ten minutes Wednesday, Thursday, or Friday morning between 9:00 AM and 10:30 AM. A semi-structured format with set topics and pre-developed questions was used. The tone was conversational. Unlike the structured format which is standardized with respect to the wording of questions and their sequence, the approach adopted, provided the freedom necessary to probe for the thinking behind particular responses and to tailor the questions to each child. The interviews, conducted in a quiet corner of the classroom, were composed of background/demographic questions, opinion questions, experience/behaviour questions, and knowledge questions (see Appendix C). A small, portable tape recorder, visibly positioned on the table around which all interviews took place, was used to record what was said. Recording began, with the child's permission, as soon as s/he was seated in the chair to my left. The recorder was stopped when the final question had been responded to and the child thanked. All audio tapes were transcribed after the final interview.

THE INSTRUCTIONAL PHASE (Overview of the Study)

Science instruction began the Monday following the interviews. In her creation of the daily schedule, Lauren slotted science for the sixty minutes immediately following morning recess on Monday and Thursday. We generally ran beyond 11:40 AM and into clean-up time scheduled five minutes before the classroom-based lunch and mid-day recess. The recommended time allotment for Kindergarten through Grade 3 science is seventy-five minutes per week, or what one determines as "sufficient time to cover the entire program for any given year" (Manitoba Education and Training, 1991a, p. 5). The decision to allocate approximately one hundred fifty minutes per week was in part a response to Cecile's desire to schedule science for more than what amounted to fifteen minutes each school day and in part to my conviction that a number of language arts, mathematics, fine arts, music, and dramatic arts objectives would be met through the lessons making up the science curriculum.

The curriculum in science, as it was developed, was the program in science. Embedded in the lesson plans for a unit were the design tools, conceptual models (as defined by Glynn and Duit, 1995), exploration activities, elaboration activities, forms of assessment, and variations of the SCIS invention phase and what Hunt and Minstrell refer to as "a 'benchmark' problem situation" (1994, pp. 58-60). The units began with interviews. Although it has been shown that older children capable of expressing their thinking on paper provide sufficient data when a pre-instruction quiz is utilized, such an approach would not have been suited to the five to eight year old children in the study. A group interview was also eliminated as a possible means of eliciting intuitive beliefs and conceptions as it was the initial ideas of individual children that were desired, not a general impression of the sorts of ideas children may have constructed by this age or construct while listening to one another. The pre-instruction interviews were followed by lessons designed to help children to begin to build conceptual models within specific domains of biology that could be activated and called upon in real world and school science contexts and at the same time to begin to develop their ideas toward an understanding of the nature of science.

As a rule, lessons were composed of three parts. These were benchmark-invention, elaboration, and enlargement. In the life cycles unit, for example, it was decided that the red thread or big idea by which all lessons were to be united would be the notion of pattern. It made no sense to think of a cycle without an understanding of the concept of pattern and repeating pattern which a cycle was eventually defined as being. Accordingly, the first lesson began with three Scottish kilts made from a Gordon tartan, a Stewart tartan, or a MacMillan tartan and a story about highland clans and the production of fabric and fashioning of garments in ancient Scotland. We looked carefully at the colours and construction of the kilts and illustrations of highlanders in their tartan clothing. This was followed by a discussion of family and what it meant to be a member of an ancient clan where everyone shared the same surname, could trace their great, great grandparents back to the same man (father) and woman (mother), and lived within walking distance of one another. Clan members, regardless of age and gender, also wore the same tartan, designed by the clan's weavers. So I asked how they could recognize a family member, often at a distance, on crowded market days. When they responded, "their tartan", I asked how one could tell a Stewart from a Gordon (the kilts having been placed at the opposite end of the classroom from where we were seated) when these tartans share many similar colours (black, forest green, and yellow). The children immediately realized that it was due to the placement of the coloured vertical and horizontal lines, and the fact that there was no red in the Gordon tartan and no bold lines of yellow in the Stewart tartan. I then told them that the clan weavers in designing a tartan usually began with a block composed of different colours and widths of lines and then repeated this block to create a tartan. The initial block was called a sett. I asked if anyone could find the sett in the Gordon tartan: "What was the block of colours being repeated over and over again?" Several children volunteered to point out the sett, and drew around it with their fingers an imaginary square or rectangle. We did the same with the MacMillan tartan. When the discussion had run its course, the term, pattern, was introduced, by asking if anyone before today's lesson had heard this word being spoken. Several mentioned the use of patterns in sewing. We then discussed whether or not a sett could be considered a pattern. I suggested that they think about a pattern as being a sett that is repeated over and over. At this point, the elaboration phase of the lesson began. As will be seen, elaboration, in the context of lesson planning, involved both reinforcement and application of the concept invented in the benchmark lesson. Given what is currently know about memory, it was believed that this phase would move an idea in short term working memory into long term memory in a form that could be recalled, re-worked, and used in future contexts whether in or out of school.

We began with the children and involved them in active pattern making. First, they were asked to line up in a way that the two people standing to their right and left would be a gender different from their own. "Had they made a pattern?" "How did they know?" "Could they locate the sett?" Then they were asked to count off, 1-2, 1-2, 1-2... All of the 1s were to sit on the floor and all of the 2s were to stand on their feet. "Had a sett been created?" "Could they identify it?" "Was there a pattern?" "Why did they believe that there was, or was not, a pattern?" At this point the 2s sat on the floor and were asked to clap while the 1s to their left and right barked in succession (that is, bark-clap-bark, bark-clap-bark...). The children then became bears and frogs. The frogs squatted on the floor and made a croaking sound, and the bears rose up and growled. From the pattern making based on their positions relative to one another, we moved to patterns based on sound that each child could produce by themselves (*e.g.* clap-clap-snap, clap-clap-snap...) and finally to patterns based on colour or shape, and eventually colour and shape using pattern blocks. I began by laying out a colour pattern on the floor and asking the children if I had made a pattern. If the response was, "Yes", a child was invited to point out the sett and tell how many times the sett had been repeated in the pattern. If a child disagreed, s/he was invited to present the visible evidence in support of the opposing view. The children were then asked to identify and repeat a teacher-made sett in order to make it into a pattern. In the last ten minutes, pairs of children selected a bag containing between fifty and two hundred pieces of four objects, and attempted to arrange the objects in an assortment of patterns for which their partner was to identify both the sett and number of repeated setts.

The next session began with an enlargement activity, linking what had been learned about setts and patterns in the preceding lesson to a context very different from the ones in which the concepts had been introduced. Enlargement, for the purposes of the science program, differs from enhancement in the scientifically valid relationships that are constructed between an invented concept and other concepts. Although enlargement will likely cause modifications in, and, therefore, enhancement of, the invented concept, the intent is to begin the construction of conceptual models. An illustrated book, titled *Snails* (Coldrey, 1991), was used to talk about and discuss land snails and the life this gastropod is known to live. The following field notes give a sense of the thinking the enlargement phase encouraged and the conceptual relations being constructed.

We gathered together on the floor in front of the white board (children sitting on the floor, Lauren and myself on small chairs). I didn't read the book to the children, but rather showed them the illustrations and talked about the snail's life. I began by showing a picture of a snail and how it must stay in the shade where it is either moist or damp. We talked about the snail's anatomy (shell and foot) and its slime trail. We talked about the shape of the shell. Willie said that he had pond snails in the water near his house that looked like the illustrations in the text. Since we were reading about land snails, and the illustrations were of land snails, I wondered if pond snails might have different shells. He didn't think so. Several children wondered if the snail could come out of the shell. I told them that the snail's shell is as important to the snail as the turtle's shell is to a turtle. We felt our ribs, and I told them that the turtle's ribs are a part of its shell, so it could never come out of it. Similarly with the snail, except that there are no bones connecting it to its shell. The shell protects the snail's body. Some students thought that they had seen a snail without its shell. I wondered if they may have seen a slug which looks *very much like a snail, at least the snail's head and foot and slime trail. I mentioned mating and showed them the illustration of the snail laying its eggs. We talked about the shape and colour of the eggs, and the fact that they are not laid on the ground but rather in the ground. Willie was very curious about the illustration of the centipede "stealing" an egg. He wondered why the adult snail, the mother, specifically, didn't take it away from the centipede. (Inagaki and Hatano would have loved this conversation!) This was a perfect time to mention the fact that not all animals stay with their young. So, not all animals are dependent when they are born. The adult snail was no longer needed by the eggs. They would hatch on their own. We then looked at the illustration of the developing snail eggs. We talked about the change in the egg from the previous illustration. Now we could see the developing snail: its shell and the eyes on the appendages or stalks. I asked the children to think about the eggs that they eat and the egg in which the snail is developing. Could they see any differences? Well, "the snail's egg is a circle" and it's also " like a ball". I wondered if they could we see into a chicken's egg. The snail's egg is almost like looking through glass. It's practically transparent (translucent is the word Lauren uses on the 19th). The next page showed the snails hatching out of their eggs. I mentioned that the first food that a snail would eat would be its own shell. Several children wondered if a snail might eat another snail's shell. (Good question!) Since they are fundamentally vegetarians, I said that I thought they wouldn't, but I wasn't certain, that this was a very good question to have asked, where might we begin looking for an answer. We then talked about the food a snail would eat. It doesn't have a mouth with teeth like ours, but rather scrapes the top layers off leaves for food. We turned the page and pointed out the changes we could see in the illustrations that portrayed a small, immature snail and an adult. They saw that the adult's shell had more colour, that there was a pattern on the adult shell that wasn't obvious on the youth's, and that the adult shell was bigger. So we discussed what happens to the shell as the snail eats and grows. The snail doesn't molt like the snake or young grasshopper (nymph) when they get too big for their bodies, but has to add a new spiral to its shell to make room for its bigger size. Using fingers, we traced the spirals in the* *illustration and saw that it had made 3 complete turns. Then we talked about the age at which a snail stops growing (1-2 years) and how it prepares for the winter. It can't fly south, it's too slow to walk to places where it is warmer, so it must stay put. But could it just hide under the leaves as it does in the summer and survive? Someone suggested that it probably sleeps. Someone else thought that it might hibernate like the bear. And it does. It pulls itself into its shell and plugs the end and spends the winter like this, never doing any of the things it would be doing in the spring and summer and autumn when there is plenty to eat. When the weather becomes warmer and plants begin to germinate and leaves begin to grow, the snail comes out of its plugged shell, begins to eat again, mates, and lays eggs. "The pattern starts over again," Marc exclaims! (Perfect closure!)*

At this point the children were asked to curl up into an egg shape, to mimic the snail's egg. Then they were to mimic the snail hatching out of its egg. How big would its shell be? How could they position their bodies to show that they were a hatchling and not an adult (slightly hump the back)? Where are the snail's eyes (at the ends of the hands)? Finally, the adult stage: a big hump and longer stalks with eyes. How about the adult in hibernation? Do you see the foot? Do your see the eye at the ends of the stalks?

We then had the children in groups of three make a sett of the snail egg, snail hatchling, and hibernating adult. Then the children formed a semi-circle, still in their sett, and we made a pattern. I tapped my hand on their head as I went around saying" egg-youth-adult, egg-youth-adult...". "What is our sett?" "How do we know that we have made a pattern?"

The life cycles unit concluded after thirteen weeks of lessons very much like those described above. In the 09 September to 06 December interval, eight periods for science were lost to school closures as a consequence of snow fall, relocation, and national holidays, to a classroom Halloween party, student-led conferences, and a day late in September when Lauren decided not to schedule a science lesson so that all three classes would again be in synchrony. The thirteen weeks represented eighteen sessions or approximately 1350 minutes (22.5 hours) of instruction in science. The post-instruction interviews, conducted during the second week of December, differed from the pre-instruction interviews in the greater number and kinds of questions asked (see Appendix E) and responded to and, therefore, duration (range: 20 to 36 minutes; mean: 29 minutes). The questions were application questions designed to reveal the conceptual models under construction. That is, each child responding to a question called upon his or her conceptual model, implicitly taught during science lessons, to describe, interpret, and explain phenomena not previously encountered.

DATA COLLECTION

For the sixteen weeks over which the study was conducted several methodologies were utilized. These were (1) the audio taped pre- and post-interviews described above, (2) informal conversations with Lauren and Cecile, (3) conversations with the children when they approached me, outside of the time scheduled for science, with questions, observations, and "wonderful ideas", (4) written and pictorial artifacts of the children's "scientific" thinking and seat work, (5) photographs taken by both Lauren and myself of the children during science lessons, and (6) descriptive field notes of science lessons with my observer comments as the investigator-teacher.

The main bodies of data drawn upon for this study were field notes and the transcribed post-instruction interviews. The descriptive field notes (6), that included the conversations listed in (2) and (3), were used as records of social interactions in the negotiation and construction of meaning and as formative forms of evaluation. That is, by embedding assessment in instruction, they helped to make clear those areas where children required additional opportunities for presenting, discussing, questioning, clarifying, and defending the conceptual models being formed as well as those areas where they simply possessed knowledge in pieces with gaps and/or few established relationships. With the exception of the small number of works completed during science lessons, the written and pictorial artifacts (4) were not utilized. The majority were Lauren's use of the science being presented as the context for language arts tasks. These particular written and illustrated worksheets in my possession, whether accomplished independently, collaboratively with peers, or teacher dictated/directed, were worked upon without my knowledge and completed while I was not present and for this reason were not analyzed. The photographs represent silent records of the children's involvement in the explorations, activities, readings, and discussions that help to make visible the enacted and experienced curriculum.

ANALYSIS

Bogdan and Biklen (1992, pp. 185-186) suggest that it is useful to think of data analysis as falling into two modes. In the first, analysis and data collection are concurrent. At the point when data begin to appear redundant, adding little that is new to the study, and field work is brought to a close, analysis is essentially finished. In contrast, the field work ends in the second mode before an analysis of the collected data is begun. Their counsel to beginning researchers is to borrow strategies from both, if only to give data collection a focus and direction. Irrespective of this position, there was no other option for the study being reported. Lesson plans, with the embedded strategies and design tools believed to help children to build and develop conceptual models by linking what they know and understand with what is believed to be a more scientific perspective, however elementary, requires that analytic induction begin with data collection.

From the first pre-instruction interview and the moment teaching began in September, the children were encouraged to share their ideas by bringing them into the open for refection and discussion. Regularities and patterns in the children's untutored beliefs and conceptions became the coding categories to organize the first pieces of descriptive data collected during the teaching of a science unit. As a result, the understanding and explanations presented prior to and early in a unit's lessons became the information from which personal, mental models could begin to be revealed, perceived, and built upon. Regularities and patterns occurring in the data collected during the subsequent weeks of instruction became the categories by which changes in the development of children's understanding could be detected and emergent conceptual models could begin to be known. The transcripts of post-instruction interviews and field notes made at the conclusion of an instructional unit were used to refine emergent categories. These categories would be used for two purposes: to decipher and re-construct the system of concepts, features and relations constituting the conceptual models that teaching and social dialogue would have helped children to construct; and to determine the ease with which the appropriate model, however perfected, was activated in the appropriate context.

Like the properties a scientist may use to sort objects into the appropriate classification groups, coding categories are chosen for particular purposes. The categories used for data analysis in the study before you are those believed to permit the elucidation and description of children's developing conceptual models in one area of biology. They are, as well, those thought to allow for the identification of concepts, in the context studied, that are accessible to young children and can be learned with meaningful understanding through guided experiences and presentations (Howe, 1993) and those that are too challenging (Metz, p.1997).

[1] Jill, the reading recovery specialist and early years teacher, was not responsible for the science instruction her students received. This was a task that, I later learned, Lauren had either requested or been handed.

[2] Teacher's Guide for Behavior of Mealworms (ESS, 1966b); Teacher's Guide for Brine Shrimp (ESS, 1969c); Teacher's Guide for Butterflies (ESS, 1970e); Teacher's Guide for Eggs and Tadpoles: Development of Living Creatures (ESS, 1974b).

[3] Organisms, Teacher's Guide (SCIS, 1968) and Life Cycles, Teachers Guide (SCIS, 1970c)

[4] Part A, Classifying 3 – Classifying Animals; Part B, Classifying 4 – Observing Living and Nonliving Things; Part B, Classifying 5 – Variation in Objects of the Same Kind; Using Space/Time Relationships 6, Part A; Part C, Observing – Observing Animal Motion; and Part C, Communicating 6 – Stages in Life Cycles (AAAS/Xerox Company, 1967b, c, and d)

CHAPTER FIVE

PATTERNS AND CYCLES: HELPING CHILDREN TO LEARN SCIENCE

The results are organized in three sections. The first presents a summary of the children's responses to twelve pre-instructional interview questions. The second focuses on the teaching and learning associated with the instructional lessons that became the life cycles unit. The third presents a synopsis of the children's responses to eight post-instructional interview questions.

CHILDREN'S RESPONSES TO THE PRE-INSTRUCTION INTERVIEW

Sixteen of the seventeen children in the study were interviewed. Patrick (Grade 3) was absent or catching up on school work each of the three consecutive mornings interviews were scheduled. For obvious reasons, I chose not to elicit his ideas once instruction was underway. Moreover, Roslynn (Grade 1) would not permit the recording of my questions or her responses to them. The uninterrupted scheduling hindered accurate recall of the ideas she expressed. As a result, the data represent the responses of fifteen of the children whose recorded interviews were transcribed.

DATA FROM QUESTIONS 1 THROUGH 3:

1. Where do you live? (Maple Hills, Eau Claire, Marshfield)
   Do you live in the town of __________ (Maple Hills, Eau Claire, Marshfield) or out on a farm?

2. Does your mother or father have a garden?
   What did you grow in your garden this year? (flowers, vegetables, berries, *etc.*)
   Were you able to help your __________ (mother or father) plant the garden in the spring?
   What kinds of things did you help plant? (seeds or starter plants)

3. Do you have any pets (or animals on your farm)?
   Can you tell me about them?

	Area of Residence				Garden(s) on Property		
Name	Farm	Rural	Village	Pets	Flower	Vegetable	Helper
Willie		Yes		Cat	Yes	Yes	Yes
Danny			Yes	Dog	No	Yes	No
Debbie			Yes	Dog	Yes	Yes	Yes
John			Yes	None	Yes	Yes	Yes
Anne			Yes	Dog	Yes	Yes	Yes
Cindy			Yes	Cat	Yes	No	Yes
Robert	Yes			Dog and Cats	Yes	Yes	Yes
Scott			Yes	Dog	Yes	No	Yes
Reena		Yes		Cat	Yes	No	No
Ken			Yes	Cats	Yes	Yes	Yes
Sara	Yes			Dog	Yes	Yes	Yes
Annie	Yes			Dog, Cat, Horses, Rabbit	Yes	Yes	Yes
Marc			Yes	Fish	Yes	Yes	Yes
Cathy			Yes	Dog and Cat	Yes	No	Yes
Michael		Yes		Dog	Yes	Yes	Yes

Three of the children live on farms, three live in the country, and nine live in three villages within the school's catchment area. I placed Willie in the country, although he did not give this answer directly. When asked, "Do you live in Maple Hills, or do you live out on a farm?" he replied: "Well I live, I live at a house, but my dad doesn't have a barn. He only has a shed for a red tractor. But he's just a little tract, he's just a little farmer with no other tractors, only one". It was not until Question 4, when he said that he would not have a Kool Aid stand because, "...our store is a flower store, cause we have so much flowers that have grown up at our house", that I classified his residence as country.

All of the children had mothers who gardened. The kind and extent of the gardens varied tremendously. Cathy, for example, said: "We don't have a garden." Her mother grew flowers. When I asked if her mother grew her flowering plants from seeds, she responded: "Ah-h,.. a couple with seeds and couple were grown already." Similarly, Cindy's mother had flowers, planted as seeds, around the perimeter of their house, and the flower beds of Anne's mother were planted with greenhouse varieties already in bloom. Reena's mother had flowers in a rock garden.

The vegetable and flower garden that had customarily been planted by her mother, didn't get tilled and sowed in the spring. In contrast, Michael's mother had a garden in which she grew "tomatoes, cucumbers, squash, strawberries, corn, sunflower seeds, um-m, potatoes, pumpkins, and more of those um-m carrots, and um-m the white kind of carrots, whatever they are [parsnips]... foil tomatoes and some apples." His family also had a choke cherry tree.

Just as the gardens varied so did the children's participation in the sowing and tending and harvesting of the vegetables and/or flowers that were developing. Danny and Reena had never assisted their mothers. Marc's participation was limited to planting a marigold and a nasturtium that he had grown from seed the previous school year. Scott helped his mother put vegetable and flower seeds in the ground in the spring, but once in bloom, he said: "I don't go too close to the flowers. There's always bees around, and wasps." Robert seemed less enthusiastic about gardening than livestock, or perhaps his farm chores simply involved work with his father more often than his mother. His comment, after stating that he helped his mother in the garden was: "I planted corn crops, stuff like that." These experiences contrast sharply with those of Willie's. Willie "got to help mom plant her potato plants", and in the middle of Question 4, he began talking about his family's recent project with willow propagation. The following is an excerpt from this conversation:

> Willie: And do you know what? We planted a big willow forest, just with sticks with roots, in our back yard, by the gravel pile."
>
> McMillan: And how does it look?
>
> Willie: Well, the sticks didn't grow yet.
>
> McMillan: Well, they should. Right?
>
> Willie: Yeah, but they don't have any roots on 'em yet. But we just found them laying around at the house.
>
> McMillan: Ok.
>
> Willie: That, they just fell down.

McMillan: Ok.

Willie: And we just planted them in our back yard.

McMillan: That will be nice when they grow, though. You will have protection [a windrow]. Right?

Willie: Yeah. It will be a bush.

John was the only child to grow up without a pet. Anne's dog had died when she was young, and she said that she was "too little" to remember it. Reena's cat was a "gramma cat". At the time of the interview her family had this one pet but was "going to get two more, a kitten and um a dog." Danny's Cocker Spaniel and Debbie's Shih Tsu were older than the six years Danny and Debbie had been alive. Danny, however, said that he "saw [Sammy] as a puppy." Scott and Michael acquired their dogs as puppies when they themselves were five and "four or five" years in age, respectively. Cathy had both a cat and a dog that had become a part of her family as kitten and pup. Cindy and Ken had both lived with kittens that had grown up to become cats at the time of the interviews. When Willie was asked if he had had his cat since it was a kitten, he responded: "Nope. I ju, I-I-I, um-m-m, my brother found it. But we got it from the pet store, but it got lost once, but then it came back." I took this to mean that his family had not purchased a kitten. Marc was the only child with fish. Sara, one of the three children growing up on farms, responded to the question with: "I only have a dog." Her father was a grain farmer with no livestock. In response to Question 6, however, she said: "We used to have kittens. That, um-m, Furball, she used to be, um-m this big [uses her hands to illustrate length] and now she's that big, but she died. She froze in the winter." A grain farm was the same environment in which Annie lived, but in addition to a dog, Annie's family had a "cat, a bunny, three horses and," she said, "...we're gonna get two more [horses]..." and "we're going to get a goat. Like a pigmy goat." When Robert was asked if there were lots of animals on his farm, he answered, "Just cows, and a cattle dog and cats." The cats were not house cats: "They stay in the barn." In response to the question, "What's a cattle dog?" Robert replied, "It's on [two second pause] the [two second pause] so we don't have to chase the cows in. The dog would chase the cows in." He lived on a dairy farm, but cows, a dog, and cats were not the only animals present. When he was shown the acorns (Question 4) and asked if he knew what they were, his answer, "Well, I know because we have pigs." Moreover, when he identified a photograph of a chick (Question 12) after being asked what it might be, he answered: "A chicken. We used to have some chicks." Finally, when asked if he had ever seen a frog (Question 8), he said: "Yeah, we have lots on our farm."

DATA FROM QUESTION 4

4. Do you know what I have in this bag? (acorns)
   What do you think would happen to this acorn if we put it in the ground and made certain that it got plenty of water and sunshine?
   Now imagine that you have an oak tree in your yard, and it's about my height when I'm standing. It's a hot, summer day and you decide to have a lemonade sale. So you get together everything that you need and set up in the shade of the oak tree. And, so that people going by will know how much you're charging for a glass of lemonade, you make a sign that shows the price. You get a hammer and nail, and you nail the sign to the oak tree at about your eye level. Now, at the end of the day, when you've sold everything, you clean up. But there's a problem; you can't get the nail out of the tree. You tell your Mother and Father and they say, "Don't worry. The nail won't hurt the tree." So, you leave the nail in the tree. Now, in about ten or twelve years you go back and look at the tree, and it's higher than the ceiling (>3.5 meters). You remember your lemonade sale and wonder where the nail you left in the tree would be. Where do you think you would have to look to find it?

Willie, John, Robert, and Ken, identified the seeds in the bag as acorns. Willie and John had "acorn trees "in their yards. Robert had once fed acorns to his father's pigs. Marc knew that the objects in the bag were seeds, and thought that that they might have been from a pinecone. Cathy believed that they were nuts. When asked what they might have come from, she responded: "They come from.. I don't know." Michael identified the acorn that he was given to hold as "a walnut or whatever." Six children, Danny, Cindy, Scott, Reena, Sara, and Annie, had no idea what the acorns might be. They had never before seen such objects.

The four boys who identified the acorn by name, said that it would either grow into an oak tree (Willie) or "an acorn tree" (John, Robert, and Ken). When Marc was asked what would happen if an acorn were put in the ground and given lots of water and sunlight, he replied: It would grow into an oak tree." Cathy's response to the same question was: "A tree will grow. It [the acorn] gets bigger, and a tree will grow." Michael answered the question with a question: "A tree?" Six of the eight children who were told that the objects in the bag were acorns from an oak tree, said that acorns would grow into oak trees. The answers were generally not as clear and unequivocal as Cindy's and Scott's who replied: "It will grow into an oak tree" and "A-a-a oak tree would grow", respectively. Reena, like Michael, answered the question by asking a question: "It would grow into the ground and be an oak tree?" Sara and Debbie simply said: "It would grow." The following excerpts from their interviews help to clarify what they meant:

> McMillan: And what does that mean though? Would this [acorn] just get bigger? Would we just get a huge acorn?
>
> Sara: Yeah. No. You would get a tree, and then the tree would grow out acorns.

> McMillan: What does that mean though, that it would grow?
>
> Debbie: It gets bigger and bigger.
>
> McMillan: And what does it look like?
>
> Debbie: It will be an oak tree with leaves on.

When informed that the objects in the bag were seeds, called acorns, from an oak tree, Danny also said that they would "grow" if planted. His response to the question asked of Sara above was: "Yeah [it's going to be a bigger acorn]." When asked, "Would it end up looking like a pumpkin or a squash?", he replied, "Um-m" and began nodding his head up-and-own in the affirmative. Anne's understanding and responses were similar to Danny's as the excerpt immediately below reveals:

> McMillan: If I were to take this acorn and plant it in the ground, like you did the flowers in your yard, what do you think would happen to it?
>
> Anne: It will grow an acorn.
>
> McMillan: It will grow an acorn. So does it just get bigger, like you get bigger, and so eventually we'll have a big acorn maybe the size of this table (diameter approximately one meter)?

Anne: Nods in the affirmative.

McMillan: Do you know that this comes off of an oak tree?

Anne: Nods in the affirmative.

McMillan: So do you still think it would just make a big acorn?

Anne: Nods in the affirmative.

McMillan: Yes?

Anne: Nods in the affirmative.

McMillan: Ok.

Fourteen of the fifteen children responded to the final part of Question 4. Danny, who realized he was missing the beginning of morning recess, had become too distracted to continue the interview and was released to join his friends. Of the fourteen who answered, thirteen believed that ten or twelve years after the nail had been left in the tree, they would have to look up to see it. The height to which they would have to look, however, varied considerably, as the following responses show:

Name	Location of the Nail in the Tree
Willie	"Right up to here" [uses hands to indicate a rise of about 30 centimeters]
Debbie	"It would be a little higher. Cause it's growing. The oak tree's growing. And it would be harder to get. Because you would, you couldn't reach it."
Anne	"The nail will go up. Because the tree's growing and the sign goes, and the nail keep, goes with it, because it's stuck in."
John	"About.. right here" [stands up to show with his hands where he thinks it will be: about 30 centimeters higher].
Cindy	"Way up high."
Robert	"Because the tree will grow. It [the nail] won't be in the same spot. Right… Like here [indicates with his hands a rise of about 30 centimeters)."
Scott	"Almost at the top. Because um-m, cause the, cause it, cause it's [the tree] is growing [and brings the nail along with it]."
Reena	"Higher up. A lot higher up."
Ken	"Way taller. Because the tree grows, and it [the nail] just stays in the same spot, but the spot that it's in just goes higher."
Sara	"It would be in the middle."
Marc	"Right up here [uses his fully extended arms and hand to show the height]. Because the tree would have grown, and the nail would have come up with the tree."

Cathy	It'd [the nail] be almost at the top. Cause the tree will grow higher, and the nail will go higher."
Michael	"Higher. Ah-h, ah-h, ah-h. because it [the tree], it starts to grow when, when, after a few years it starts to grow [and takes the nail with it]."

Annie, alone, claimed that "it [the nail] would stay in the same place." When asked, "Why do you think so?", she responded, "Because, the nail won't grow." This belief was held even when asked: "But it is the tree that is growing, so even though the tree gets taller, the nail will be in the same spot?"

DATA FROM QUESTIONS 5 THROUGH 7

5. Has your _____ (pet: cat, dog, horse, fish, bird, *etc.*) changed as it has gotten older? How has it changed?

6. Can you think of other animals, like your _____ (pet: cat, dog, horse, fish, bird, *etc.*), that just seem to get bigger as they get older.

7. Have you changed as you've gotten older? What can you do today that you couldn't do when you were a baby?

Scott's dog, Max, was "not much [bigger]" than when it was a puppy, one of Annie's horses "was old when we [her family] got him" and hadn't changed in the interim, and when Marc was asked if his fish had changed as they aged, he replied: "No. Only one of them has gotten a little bigger." All of the other dogs and cats and bunny and horses had "gotten bigger" (Willie and Danny) or "bigger and more trained" (Annie), or "taller" (Anne) or "taller and wider, longer" (Michael) or had "grown" (Robert,) or "grown bigger" (Ken).

Michael's dog could "run faster [three second pause], jump higher." Cathy's cat, Gumdrops, made several notable changes: "...she got bigger and everything got, like her claws got sharper, and she got her claws, and her claws grown, and um-m her teeth grown and she lost some teeth." Ken's cat, Toby, "was really skinny" but "getting fatter". Danny's Cocker Spaniel, Sammy, "doesn't run much anymore" and preferred to "sit down." Scott's two year old dog, Max, could "walk down the stairs [without falling]" and "jump on his doghouse." When Scott's family installed a fence, he also "used to keep jumping over the fence, from the dog house to over the fence." Annie's dog could now "stay home" when the family was away for short periods: "She doesn't have to be close to us." Sara's dog, Dudley, "...used to not sniff, and now he sniffs everything."

The animals thought to change by getting bigger as they aged, included the following:

"A fish. Um-m-m [three second pause] a cat." (Debbie)

"Ah-h-h, ah, a yellow lab. Um-m, let's see, oh, um [three second pause] a black lab. Um, um-m, ah-h, let me think, monkeys? (Scott)

"A horse, and a cat. Caterpillar, a penguin, and a pig... Um. A zebra. Actually a giraffe" (Cindy, while looking at the covers of books placed on the table)

"Deer. Fox. Um-m [three second pause] rabbits [three second pause] lions." (Ken)

"Um-m. Kittens. Um-m. My dad used to have pigs. About this big [uses hands to show size]. And then, some were about this big [shows larger size with hands, arms extended], and they dies. Um-m cause they were about a hundred years old." (Sara)

"Whales. Um-m-m. Any animals? Elephants. Li.., no not lions. Only. Because the boys, while they get bigger they grow a mane. The girl lions don't change, alls they do is get bigger." (Marc)

All of the children had changed, for the most part, by getting bigger. Marc, for example, said: "I've gotten bigger-er, and I can talk and as a baby I couldn't talk." When asked if he could do other things that he couldn't do before, he responded: "Math." Like Marc, Debbie "used to be a baby" and had "grown a little bit." Now she could "stand up" and talk: "But I could talk a little bit. Like 'ma-ma,' 'da-de'." Reena had "longer hair and brown eyes" and "could run faster...read better...and draw better." When Danny was asked what he could do now, that he couldn't do as a baby, he replied: "Um-m, swing. Um [three second pause] climb a tree. Um, swim. Um-m, ju, jump off a diving board." To a similar question, John answered: "Ah-h-h, walk. Because babies can only crawl. You can flip. You can [two second pause] talk. You can eat, but babies have to swallow. Because they have no teeth." Robert's response was: "Drive a tractor. Drive a motorcycle. Ride a calf [three second pause] like, like things like that. Oh! My Dad's getting a snowmobile."

DATA FROM QUESTIONS 8 AND 9

8. Have you ever seen a frog or a toad?
   What does a baby frog (or toad) look like?

9. Have you ever seen a caterpillar?
   Do you think they change as they get older? (If "yes", ask, How do they change?, if "no", ask, Did you know that a butterfly develops from a caterpillar?)

All fifteen children reported seeing a living frog. John saw "a toad" that "was like swimming in water" as well as a frog at his cabin. Reena whispered that she had seen "just one frog" in her life. She came upon it at her family's lake property. Danny reported seeing a "huge one." Scott and his older brother "saw a black frog" that they ended up killing with wood "because it can irritate your skin." When Cindy was asked if she had ever seen a frog, she responded: "Yeah. And I kinda, when I had one, I put it in a pail and gaved it water, lots of times, and give it some grass and give it a rock so it could stand on it and dry off when it has a bath. But it just went away." Sara, on the other hand, reported having a frog for three years. She said: "Yes-s-s. I don't have [two second pause]. But I've, when I catch a frog. Since I had a frog when I was one, and then I let it go when I was four years old." Like Robert who claimed to have "lots [of frogs]on our [his family's] farm", Willie reported "tons of frogs at home" and "tadpole eggs in our pond."

Willie, Debbie, Anne, Cindy, Marc, Cathy, and Michael had heard of tadpoles, and knew that it was a tadpole that emerged from a frog's egg. When Cindy was asked if she knew frogs laid eggs, she replied: "Tadpoles. They are little baby ones, and they're called tadpoles, but they have to be in water first." In response to the question, "Does the tadpole look like the adult frog?", she said: "No, they would never look like a tadpole." Marc described a tadpole as looking "like a little fish." Anne said that "it has a little tail, and [two second pause] no wings." When asked if she thought that the frog hatching out of an egg would look like the adult frog, Debbie responded: "Um-m. A-a-a. I forget what they're called. No, not yet, because they're um-m, little insects that, not that, cause I forget what they're called. And soon they're going to get legs, and [two second pause] arms. To the same question, Willie replied: "No. They just have big heads on, like right here [points to his own head], and they have tails on the back. So they can swim."

Reena whispered that she "didn't know" about baby frogs, only that what comes out of the eggs must be "gooey." The question asked had been: "So did you know that they come out of eggs as well? But the egg doesn't have a hard shell like a bird's egg. It's just like an egg in Jell-o. It's a big gelatinous mass and there are a whole bunch of them. So what do you think the frog looks like that hatches out of an egg?" The other children, Danny, John, Scott, Robert, Ken, Sara, and Annie described the baby frog as a "little frog" or a "small frog" that gets bigger as it grows. Ken, for example, said that he thought frogs emerging from eggs would be "probably normal like babies or like, they're small." Scott's more detailed response is given in the following excerpt:

McMillan: Did you know that frogs lay eggs?

Scott: Yeah.

McMillan: They're not like birds' eggs though, are they?

Scott: No.

McMillan: How are they different?

Scott: Because, the, um, the, they're kind a smaller so you can't see them.

McMillan. Ok. So what comes out of a frog's egg as it hatches?

Scott: A frog.

McMillan: What does it look like?

Scott: What, what, what it um, what, what, what his mom looks like.

McMillan: Ok. So it's just a smaller version of its mom?

Scott: Um-hum.

McMillan: And as it eats and gets older, what happens to it?

Scott: If it's a boy, it turns like its dad, and if it's a girl, it turns like its mom.

With the exception of Annie and Ken who didn't know about "baby butterflies," Anne who said that the butterfly emerging from an egg would look like "[a] little moth," and Danny who drew a caterpillar as "growing a little bit" and then a lot but never becoming a butterfly or moth, the children understood that a caterpillar "turns into a butterfly." Differences existed in the language used to describe the pupa and, in two instances, the duration of the pupal stage. For example, when Willie was asked, "What happens to a caterpillar as it gets older?", he responded: "It turns, it, it makes a ca, it makes a, a canoe and turns into a butterfly. Flap Flap [moves his arms up-and-down like wings]." For Debbie and Cathy, Willie's canoe is a "little nest." Debbie's response to the same question was: "Um-m. A butterfly? Because it, it's a [two second pause] caterpillar, then it finds a nice place to build a little nest, and you, and it goes in and waits a couple of years, and then it springs out to be a butterfly." Cathy, who was asked, "Do you think that when the caterpillar hatches out of the egg, it just grows into a bigger caterpillar?" gave the following reply: "No, it [three second pause]. Well, yeah. It grows into a bigger caterpillar, but when it goes in the [three second pause] little nest thing, he goes into a butterfly." Both Sara and John referred to the cocoon/chrysalis as a "raccoon" and "raccoon egg", respectively. For Sara, "it [the caterpillar] has to make a raccoon, and then it goes inside for a couple of days, and then it turns out as a butterfly." John said: "...it [the caterpillar] goes in a rac [four second pause]. A, sort of like a raccoon egg, and then it opens, and then it's a butterfly."

During the interviews, six of the children spoke about the growth of butterflies. Scott believed that the adult would grow "just a little bit" after emerging from the chrysalis, as did Michael, who said: "They grow a little bit. Their wings. Their body." Willie, Debbie and Reena thought that the adult would not get bigger. That it would always be the same size. This was what Sara also believed. When she was asked if the butterfly "turning out" of the "raccoon" would grow, her response was: "Um-m [three second pause]. No-o, it just flies." Willie and Sara, however, did not believe this was the situation for other insects. When Willie was asked, "Do you think when the butterfly comes out of the "canoe" that it gets bigger? Does it grow?", he replied: "No they just stay how they are, but the wasps that are little grow up." To the question, "Do you think that a little fly, that maybe bothers you at a picnic, grows into a bigger fly?", Sara answered: A-h-h, it grows [two second pause] into a [two second pause] bee. Like a bumble bee."

DATA FROM QUESTION 10

10. What do you think changes more during its life a caterpillar that becomes a butterfly/a tadpole that becomes a frog or your ____ (pet: cat, dog, horse, fish, bird, *etc.*)? Explain.

Of the eleven children responding to Question 10, seven believed that the caterpillar or frog changed more than a kitten (Reena and Cathy) or puppy (John, Scott, Sara, and Annie) or fish (Marc). The explanations were not unlike the responses given by Marc and Sara to the question, "Why do you think so?" Marc said: "Because fish the, they don't change ver, fish don't change very much, only sometimes they get old and they get bigger, but frogs, when they're born, they change into a frog and they were like little fish." Sara answered: "Well, because. It's [the caterpillar is] just so little, and it, besides it really *does* change."

Ken thought that a cat changed more than a butterfly, but that a fly changed more than a cat. In the first example, a cat "grows, and it gets stronger claws and better grip." In the second, flies "fly around and bite people and they take up most of the place. Like, make people stay inside." Debbie said that a cat that "used to be a baby and now it's a-a adult" changed as much as the butterfly. Robert presented the lamb as an example of an animal, like the frog, that doesn't resemble the adult parent at birth. He said that the lamb makes more changes over its life than the butterfly. This was attributed to the fact that the lamb "gets more fur, and the butterfly it gets like colours all the time." Willie answered the question by saying, "It's a, it's, it's a cat and a puppy" that change most as they get older, not the caterpillar. When asked why, he mentioned the caterpillars that turn into wasps, and said: "Um-m-m, the caterpillar. Cause they turn into butterflies."

When the children were asked if they could think of animals that changed as much as the frog or butterfly, five, in addition to Robert who mentioned the lamb, named at least one. These were the following: "a spider" (Danny), "cheetahs" (Ken), "a shark and a whale, especially whales" (Marc), "a person" (Sara), and fish that begin as minnows (Michael). All got bigger. The cheetah got faster as well.

DATA FROM QUESTION 11

11. Imagine that a bird has built a nest in one of the trees in your yard, and that the bird is a robin. The robin lays five eggs in the nest that she has built in your tree. What do you think will hatch out of those eggs? (If the answer is "baby birds" or "baby robins" ask the student if it would be possible for the baby birds to be blue jays or hummingbirds.)

The ten minutes set aside by Lauren for interviewing each of the children had been spent in four cases before Question 11 had the opportunity of being posed. As a result, eleven of the fifteen children were asked about the contents of the robin's eggs. Willie, Danny, Cathy, and Michael were not.

Of these eleven, Debbie and Scott believed that "a robin" would hatch out of each of the robin's eggs. Annie answered, "more robins" and Marc said, "little robins." When asked "Why?" or "Could there ever be blue jays or hummingbirds or gold finches hatching out of those five eggs?", the following responses were given:

> Debbie: No. Because the mother lays a robin's egg, and if it's not a robin's egg it will be a wrong bird.
>
> Scott: Because um, because it, because em, because the mom is a robin and it laid robin eggs.
>
> Annie: Because um-m [5 second pause] because that's not the kind of bird the mother was.
>
> Marc: Because, um, it has to be an egg from the same kind of bird.

With the exception of Sara who answered the question, "What kind of eggs does a robin lay?", with "Um-m, special eggs, that have birds in them", the other children's responses to the first part of Question 11 did not differ from those already reported. Anne, for example, replied, "Ah-h-h, a chick? Ah-h-h, robin chick." Ken said, "Birds, baby birds." Reena answered, "A baby robin." Nevertheless, these four children, along with John, Cindy, and Robert, all believed that other kinds of baby birds could, or might possibly (Reena), hatch from the eggs laid by a female robin. This belief is expressed by Danny in the following exchange:

> McMillan: So, let's say in your yard you have, you've got an oak tree, and a robin has built a nest in that tree and it lays a whole clutch of eggs. Now what do you think will hatch out of those eggs?
>
> Danny: Ah [two second pause] babies.
>
> McMillan: And what do the babies look like?
>
> Danny: [Four second pause] Um-m-m. [seven second pause]Kind of look like birds.
>
> McMillan: Yes?
>
> Danny: Yeah.
>
> McMillan: So could it, do you think, could it be any kind of bird that hatches out? Could a blue jay come out, or a hummingbird come out of the robin's eggs?
>
> Danny: Yeah.
>
> McMillan: Just any kind of baby bird?
>
> Danny: Yep!

DATA FROM QUESTION 12

12. (Inagaki's question) Show the pictures of the baby animals (chick, penguin, piglet, foal, kitten and human baby) in the book, Growing Up. Some people like baby animals so much that they wish they could keep them as babies. Do you think it is possible to keep a kitten a kitten and not have it become an adult cat, a piglet a piglet, or does it have to become a pig, and so on. Why do you believe this is possible or impossible?

Question 12 was not asked of Danny, Debbie and Ken. Of the twelve children responding, only Robert believed that it was possible for baby animals to remain baby animals and for a baby brother or baby sister to remain a baby, without getting older. The eleven other answers and explanations, where given, are presented below:

Name	Responses: Can one prevent the growth and development of an animal?
Willie	"No. Cats grow up. Puppies grow up."
Anne	"You can't. Cause, a-h-h [three second pause]they [three second pause]don't [two second pause] they have to grow, and they eat more and more and that makes them grow too."
John	"No because it just grows. You can't stop a baby either."
Cindy	"Take out their brain. No. It has to grow into a dog."
Scott	"No. Because it, because a, because it, because some, because it, it will die. Because um, from getting too old. It starts to um, just, just starts walkin' slower, runnin' slower."
Reena	"Um. Put a collar on it and keep it, and get a litter box. No. Because it get, has to get older, and then you call it a cat."
Sara	"Nope. Well, you can keep it until it grows up and then you can let it go. You can do it like that."
Annie	[Shakes head for side-to-side.] "Because it has to grow bigger to make more kittens. Well, because they have to grow to get stronger and um-m [five second pause] make more."
Marc	"No. Because they grow and they can't stop it from growing. Cause all, everything grows."
Cathy	"No because it keeps on growing. You can't stop it from growing."
Michael	"It has to be a cat. You can't [three second pause]. Only if you don't feed it or [three second pause]. Anyway after years pass, you get bigger and then smaller again. When you're old people, you get to go smaller. You're just going to get a little bit short."

THE ENACTED CURRICULUM

It is not an easy task to take thirteen weeks of science lessons and present the salient points that will enable more than biased conclusions to be drawn in the final chapter. Rather than present a summary of each day's activities and the talk that ensued, the "data" will be presented in a format that resembles a journal. Not any journal, but what I imagine the journal must be of a wayfarer on a tightly scheduled itinerary. S/he comes to the end of the day filled with as many questions as observations. These must be recorded before fatigue overwhelms all conscious thinking, and they are lost from memory in sleep and the flurry of another day. The records are no more than informal notes, photographs, drawings and artifacts picked up along the way -- placeholders for the wayfarer. These placeholders, however, give enough information for any reader who happens upon them to become aware of the lived experiences of one individual during a sojourn.

Before examining the "journal" that follows, it is suggested that the life cycles unit be read (Appendix D). As the note explains, these are the lesson plans written each week for the two teachers of early years science at Maple Hills School.

WEEK 1

Wednesday 04 September Pre-instruction Interviews

09:10 Debbie
09:20 Sara
09:30 Annie
09:50 Ken
10:00 Danny
10:10 Cathy
10:20 Michael

The biology unit begins on Monday. Lauren mentions that she would like to spend the remainder of the week discussing with the children the concepts of living and nonliving. She asks for ideas. I wonder if I should tell her about the research that has been published in this area, especially the studies of young children, the properties that they think show life, and their animistic judgments. There is the book, *What's Alive?* (Kathleen Weidner Zoenfeld) that she could use. It's a Stage 1 (ages 4 to 8), *Let's Read and Find Out Book.* This could be a nice way to begin if it's not simply read (teach by telling), but discussed. I must remember to bring it with me tomorrow morning. I have to think more about this. She needs a way to bring the children's intuitive ideas to the surface. Maybe "slime" (Borax and white glue) or "gloop" (Sta-Flo liquid starch and white glue or "goo" (corn starch and water) could do this.

Thursday 05 September Pre-instruction Interviews
09:05 Robert
09:15 John
09:25 Reena
09:35 Cindy
09:55 Willie
10:15 Marc
10:25 Roslynn

Lauren plans to read *What's Alive?* this afternoon. After Roslynn's un-taped interview (morning recess), I showed her the slime activity from *Homemade Slime and Rubber Bones: Awesome Science Activities* (William R. Wellnitz), and asked if she would be interested in having the children make this substance with white school glue and Borax. (Glue and Borax produce a cross-linked polymer that can be rolled into a ball or stretched, and, if left in the hand, will flow slowly through the fingers like mud.) I thought that it would be interesting to have them mix borax and water and then add this solution to glue (all inanimate and manufactured materials). When the children removed the slimy goo from their cup or zip-lock bag after stirring or kneading the mixture and played with it and saw that it flowed (moves on its own), she could ask questions like, "Do you think the slime is alive?", "Why do you think so?", "What does it mean for something to be alive?"

She plans to purchase the Borax after school. The children will make it on Friday.

Friday 06 September Pre-instruction Interviews
09:40 Scott

I miss the making of slime. Earlier in the week, I had made arrangements with Bob Stewart to pick up two authentic Scottish kilts that I wanted to show on Monday. To arrive at his house on time, I couldn't and didn't stay beyond the twenty or so minutes it took to interview Scott and pack up the paraphernalia I had used.

WEEK 2
Monday 09 September Setts and Repeating Setts as Patterns (10:40 – 11:20)
(Described in Chapter 4)

Several of the children, looking at the world map that Lauren and I had pinned to the wall, couldn't believe how far Scotland was from Maple Hills. But even more surprising, when we opened the books to show the clothing once worn by Scottish highlanders, was the realization that the men wore "skirts." Were they, in fact, skirts? A more careful look at the illustrations showed fabric wrapped around the waist, up the back, crossed over the shoulder, down across the chest, pinned to the "skirt" above the knee, and held in place with a belt. To cover a tall man, I told them that a piece of fabric wider than I was tall (approximately 1.8 meters or 6 feet) and longer than the classroom (approximately 14.4 meters or 16 yards) was needed. So much more than a blanket or the fabric needed to make a shirt and pants. To many of the children, this seemed incredible. The highlanders couldn't go to the store, as they would today, to buy the material or the finished clothing. The fabric had to be made. We talked about this process: the sheep and the shearing of their wool and how the wool fleece was cleaned, dyed, and spun before it was given to a male crofter/weaver to weave/make into a piece of fabric. When I asked if they thought people living at this time would have drawers and closets filled with clothes, they didn't think so, but were amazed that there could possibly be only an outfit for work and a dressier outfit for special occasions.

The discussion of clans led to the realization that none of the children lived within walking distance of their grandparents, and most cousins and aunts and uncles lived even further away.

The notion of a sett and a repeating sett making a pattern seemed conceivable as long as the set remained a-b or a-b-c and the pattern a-b, a-b, a-b... and a-b-c, a-b-c, a-b-c...
When Cathy suggested that the sett for a pattern be "cougar, tiger, cheetah" and no one was immediately certain how these three cats could be made distinct to form a recognizable sett, her neighbor said that a cat and dog would work. This sett was organized into a pattern and the room was filled with barking for several minutes.

Robert and several other children weren't certain what to look for when pattern blocks with different shapes and different colours were used in making the sett (*e.g.* if the sett was red diamond, blue diamond, yellow star, green triangle, orange triangle, they would represent it as two diamonds of any colour, a yellow star, and two triangles of any colour). The work of the children, in partners, with the bags of four different objects, tended to be a-b, a-b... or a-b-c, a-b-c... or a-b-c-d, a-b-c-d... Danny and Michael, Debbie and Steven, and Anne and Sara were exceptions.

Thursday 12 September Making Patterns (10:40 – 11:55)
(Described in Chapter 4)

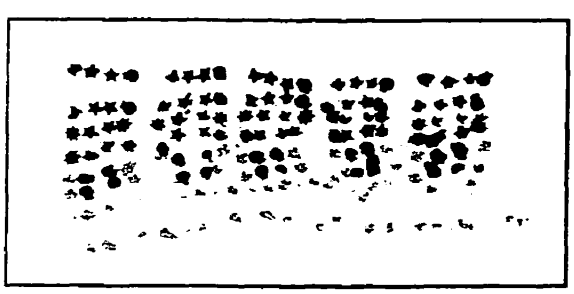
Six stations, one for each bag of objects, were established at the pods of four desks. The children could rotate when they had completed a pattern at one station, if they could see a space for themselves at another. The materials everyone wanted an opportunity to use were the stamps, especially the Crayola mini stampers (used by Anne, Reena, Sara, Ken, and Annie), the self-inking animals and the Jurassic Park dinosaurs (used by Willie, Debbie, Cindy, Scott, and Marc). Robert and Michael each made a pattern using the adhesive stamps. Danny, John and Cathy made patterns in Play-Doh and with beads.

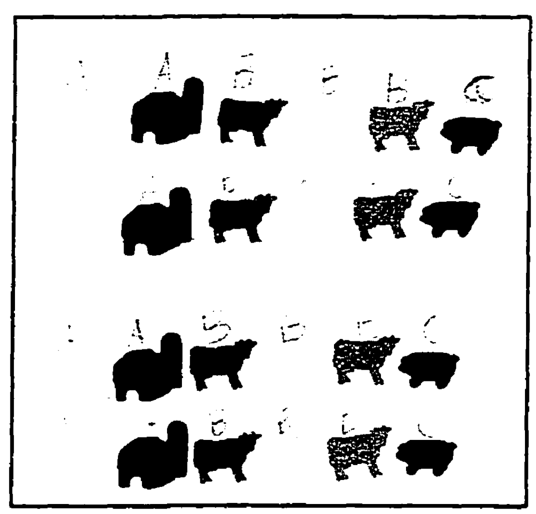
The patterns created on paper by Willie, Cindy, Scott, Reena, Annie and Marc varied only in the number of items in the sett and the number of times the sett was repeated vertically: one sett occupying one row, and each row representing one repetition. Marc's pattern was jaguar-alligator-dinosaur repeated for seven rows. Reena's sett was each one of the fifteen mini stampers repeated for twelve rows. The pages upon which these six children repeated their setts had the appearance of columns of identical items rather than patterns.

Debbie, Sara, and Ken repeated their setts horizontally as well as vertically. Debbie created the sett, frog-bird-jaguar, frog-bird-jaguar and repeated it for a second row. Sara and Ken made four object setts, repeated their setts over five and seven columns, respectively, and then for a second row.

Michael and Anne were the only two children to use multiples of a single item in creating a sett. Michael's sett was barn-barn-cow-cow-cow-pig. It was repeated once vertically. Anne's sett, ladybug-star-star-ladybug, was repeated across four columns and two additional rows.

Unlike the other children, Robert ran his three object sett (barn-cow-pig) vertically for four columns. Laid out on the page this looked like a row of four barns (red, green, yellow, blue) below which was a row of four cows (pink, pink, dark green, light green), below which was a row of four pigs (red, yellow, blue, green).





WEEK 3
Monday 16 September Recognizing Natural and Man-made Patterns in the Environment (10:40 – 12:00 NOON)

Weather: Partly cloudy, an air temperature of 15° C with a forecast high of 19° C

Science began, with the end of recess, just inside the main entrance of the school. We waited for Lauren to arrive. I asked if they had noticed any patterns in the school building. Marc mentioned the "brick-line, brick-line, brick-line…" pattern in the brickwork. When asked to point out the brick and the line he was talking about, he touched a brick and the row of mortar above and below it. There was also the pattern made by the mortar on either side of the brick that he hadn't noticed. I asked the children to look carefully at the wall, especially at the way the bricks overlapped. This pattern (a stretcher bond) was much stronger than if the bricks had been stacked one on top of the other in rows and columns.

Two girls pointed out the grid sandwiched between the glass of the entrance door and explained the pattern they saw in it. Danny suggested that everyone look at the ceiling above the doors. It had an "up-down, up-down" pattern. (This was tongue and groove aluminum. Danny's up and down were the pits or canals on either side of the flat section.)

When we moved through the door to the sidewalk outside, the children were asked if they could find a pattern in the way the concrete had been laid. Several skipped down the sidewalk calling out "big block-crack, big block-crack..." as they landed on a big block and skipped over the crack. Everyone agreed that the sett was the "big block-crack". It repeated over and over again. The sidewalk was a pattern.

Could anyone explain why it had been made this way and not as one, long, smooth strip? Before this question could be considered, Willie and Annie and Marc and Scott needed to know how a sidewalk was made. When the children who had watched a sidewalk being formed finished explaining what they had seen, Willie said that he believed the big block was a single brick, like a paving stone, and that the cracks between two big blocks were just the spaces between any two paving stones. No one could see any soil or grass in the spaces, only more concrete. Could there be another explanation? No one spoke. Had they ever seen similar kinds of spaces on bridges or sidewalks across bridges? Michael along with several other children said that they had. Had they noticed if the size of the space changed in the summer and winter? No one had thought to look, so I said that the spaces are there for a purpose. If it weren't for the man-made "cracks" (contraction joints) in concrete sidewalks, the surface would be covered in more cracks and fissures than we already see. The contraction joints allow the concrete to crack inside the joints, rather than the surface. Annie said that she had once asked her mother why the cracks were in sidewalks, but her mother couldn't answer her question. Lauren, who had arrived several minutes before, suggested that Annie explain the cracks to her mom.

The following patterns were noticed by the children as they walked through the parking lot and then skipped and hopped across the grass to the play structures:

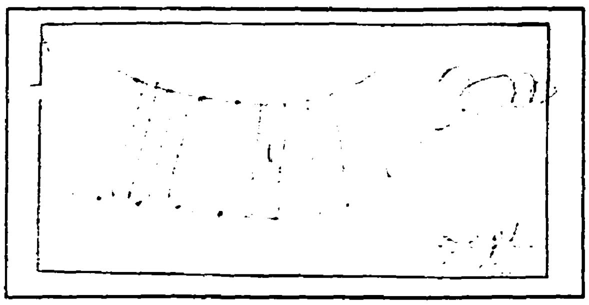
> "post-rail, post-rail, post-rail…" of the parking lot fence (Scott);
> "post-chain, post-chain, post-chain pattern" of the playground fence (Danny);
> "flat-up, flat-up, flat-up" pattern created by the links in the chain (several children at once);
> "board-space, board-space, board-space…" of the suspended plank bridges;
> (Danny wondered if the spaces in the swinging bridges were put there for the same reason the spaces were put in the sidewalk. Someone suggested that the spaces might be there so that the rain would run off.)
> "solid-space, solid-space…" of the two tires nailed one above the other (Sara);
> "in-out" pattern of one tread line on a tire (Robert);
> (Several children wondered if all tires had the same pattern of treads. We would have to look at the tires of the cars in the parking lot on our way back to the classroom. Before we left the play area, Michael pointed out that the treads on the tire swing didn't look like the treads on the tires to be climbed. What did this mean? There are different tire patterns.)

The children paused in front of a symmetrical structure of twenty-five posts that began on the left and the right with a post about thirty centimeters off the ground and gradually rose post-by-post to the thirteenth (and centre) post with a height of over a meter. What did they notice? Neil, one of the children in the class who was not interviewed, said, "big, bigger." He tapped the lowest post and said, "big" and then tapped the post adjacent to it and said "bigger". He kept going like this all the way up to the tallest post. Everyone was confused. The posts got bigger and bigger. Why was he saying the posts were "big-bigger, big-bigger"? I suggested that they look at two posts at a time. Were they arranged big-bigger? Patrick jumped up and said, "big-bigger-biggest!" His sett was a sett of three. At the midpoint, he had to change his pattern. Big-bigger-biggest wouldn't work on the way down. I wondered if they had noticed that the posts decreased in size on each side of the tallest post. If we could draw this structure on paper, we could fold the paper through the tallest post and have the pattern folded back on itself. Held up to the light, we would see that each half was the same. Everyone sat with a blank stare, more confused than Neil had made them. Michael and Patrick walked up the posts, Michael beginning on the left and Patrick on the right. We counted as they stepped from one to the next. Lauren asked if they thought they could draw this arrangement of posts when they got back to the classroom. I heard a few children say "yes", but many more answered "no".

On the way back to the school, we stopped to rest under a tree and looked up through the crown at the pattern of branching. What did they see? The biggest branches were nearest the trunk and the smallest branches were furthest from the trunk. Each branch was smaller than the one from which it grew. Was this true for all trees? How did this compare with the veins in the leaf? Was a blade of grass like a leaf from the tree?

We had run out of time. Back in the classroom there were only a few hurried minutes to show the hexagonal patterns in the corn and honeycomb (the bubbles collapsed too quickly) and the self similarity in the smaller and smaller portions of the fern frond.

Marc wondered if the corn was rotting and if this was the reason for its colour not being yellow.



Thursday 19 September Cycles as Repeating Patterns (10:40 – 12:00 NOON)

A new laminated work on chart paper had been put up on the wall. It was made with the heading, "Slime". The contents are reproduced below:

We made slime.
We worked in partners.
We mixed glue, water, food colouring and Borax.
We let the slime slip through our fingers.
We talked about the slime.
Is it living?
How do you know?

<u>Is it living?</u>

Yes	No
✓✓✓✓✓ ✓✓✓✓✓ ✓✓	✓✓✓✓✓ ✓
12	6

<u>How do you know?</u>

It is living because:
- it feels like a frog
- it is here
- it squishes around
- it feels like a snake

It is not living because
- we made it
- it doesn't have eyes
- it would have been able to walk by itself
- it doesn't have legs

it wiggled around
Jesus made us and we made the slime
it feels slimy like a frog at my lake
when we played with it, it moved around
it changes shapes
it feels like a worm
it splatted down
it bounces

it can't eat
if it was living, it would have a brain

The lesson began with a review of the snail's life cycle using the book, *Snails* that had been read the week before.

The children were shown a cross section of the snail in the *Ultimate Visual Dictionary* (pages 176-177). The illustration showed why the snail must have its shell: it protects very important internal organs (the lung, heart, digestive gland, stomach and kidney).

What organs, the children wonder. Where is the brain? Where is the heart? Does the snail have arteries? Why do they call the part outside of the shell a foot? What happens to the snail if it's in the sun? Why are there so many shells without bodies?

At this point, it was the octopus that shared the two page spread that became more interesting. Would the octopus eat snails, if the snail gave birth to little snails? Lauren asked if they thought that the octopus would lay eggs since the snail lays eggs and scientists have grouped them together (Mollusks).

John tells everyone that he has a book about skeletons, and that it has lots of skeletons of animals and lots of skeletons of dinosaurs. All of the children want to talk about dinosaurs and the dinosaur books they had or continue to own.

It's time to curl up and look like a snail egg. "Are you ready to hatch out of your egg and emerge as a little snail? Are you eating and growing into the adult?" Lauren touches each student on the head. They are either an egg, youth, or adult. Everyone holds hands and makes a circle. You're a snail again. Where are the eggs? Where are the youths? Where are the adults? Where is our sett? What have we made (an egg-youth-adult, egg-youth-adult... pattern)? Where does the pattern begin? "With me" says an egg. "No, I'm the egg" says another. Where does the pattern end?

There is no ending. The pattern begins again and happens in the same order. What is the order? "Egg-youth-adult, egg-youth-adult, egg-youth-adult..." It keeps going and going and going. We are standing in a circle. The pattern is called a cycle.

There was no time for stories or discussing natural cycles (moon phases, the four seasons, day and night). The children were given a long and narrow strip of paper that they folded in half, and folded in half a second time. When the paper was unfolded, they were asked: What do you notice? "Creases". "Bumps". Sara says "four flat pieces and three bumps". Does everyone see what Sara sees? We have four spaces, all the same size, separated by folds. Can you draw a sett on the first space and repeat it in each of the three other spaces? What will everyone end up with on their paper? "A pattern". How many times will the sett be repeated? "Three".

Michael is one of the last to finish colouring the objects in his pattern (spider-ladybug, spider-ladybug...). Debbie only finishes her sett and one repeat (adult snail-octopus-small snail).Danny makes a sett of geometric shapes. John alternates a sun with glasses and a star. Willie draws a Tyrannosaurus-Raptor pattern. Marc's pattern is a hockey puck-hockey stick-hockey net. We wrap the patterns around their head and forehead and tape them snugly in place. What happened to your pattern? "It goes on and on and on." Where does it begin? Where does it end? What is the name for a pattern that repeats itself in the same order over and over again? "A cycle."

WEEK 4
Monday 23 September Science cancelled (catch-up day for Cecile)

Thursday 26 September Revisiting the Concepts of Living and Nonliving (10:40 – 12:10)

Lauren asked if she could use the time scheduled for science to look again at the notion of living and nonliving. We would use the objects that I had placed on a table top the previous Monday for the children to explore. These included a jar of glass marbles, four different shells, two living plants (jade and philodendron) in a green plastic pot, five ladybugs in a jar with twigs and leaves, a spider in a jar with twigs and leaves, a moth in a jar with twigs and leaves, 3 plastic ants in a jar with soil, a green plastic grasshopper in a jar of grass, a McDonald's pull back "Lucy" car, a wind-up penguin, a plastic tropical puffer fish in a jar of tap water, a metallic crab with moveable appendages in a hinged, wooden box, a piece of rock with quartz, and a yellow-ochre rock. (All of the objects in jars were contained in wide mouth, 238ml Mason jars.)

The children sat in a circle on the floor. Lauren placed a sheet of paper with the word living and a second sheet of paper with the word nonliving on the floor inside their circle. She planned to send the objects one by one round the circle. The sorting would begin when everyone had looked at each one.

With the exceptions of Willie the children said the shell was nonliving. It didn't have legs. It couldn't move by itself.

The crab was nonliving. It was a toy. Michael said that he had taken one apart and there was metal on the underside of the crab's body.

The penguin was nonliving. Its legs were moving, but it was a toy. You had to turn a knob on the back to get it to move. Living things don't have to be wound up.

The fish wasn't alive. It moved in the water but only when it was shaken. It couldn't move in the water on its own. It's in the water, but it isn't swimming. Fish swim. It isn't real.

The plant was nonliving. It couldn't move in its pot. No matter where it was planted, it couldn't move. It's plastic. It's an artificial plant. The soil is dry.

The ladybugs (crawling all over Scott) were living. They were moving.

At this point Lauren asked if movement was the best criterion to use. She pointed to the chart on the wall (Is the cricket alive? How do you know? It is alive because it makes a sound, it moves by its legs, it eats food, its body cannot change shape, it has an outside skeleton, it breathes."), and read the three words at the bottom. "Water, Air, Food. If something is alive, it needs water, food, and air to stay alive. These are the things a scientist would look for to determine whether or not an object was living."

Everyone was hungry and restless. The children in Cecile's classroom were in the hall getting their lunches.

Is the rock alive? The response from the children was a unanimous, "no". Why wasn't it alive? "It can't move." "It's a rock." "It doesn't have legs." Cathy answered, "No. Because it doesn't breath air. It doesn't eat. It doesn't drink water."

Is the spider alive? "Yes", several children responded, because "I saw it moving in the jar." Annie, Marc, and Cathy answered, "Yes, because it needs air and water and food." Lauren asked, "Cathy, how do you know?" "Michael, how do you know?" They answered, "it needs air, water, and food.

WEEK 5

Monday 30 September Cycles: Focus on the Four Seasons (10:25 – 11:50)

Before recess ended, Michael came up to me to show a gift he had received for his birthday. It was a soft plastic snail. He handed it to me. I looked at it carefully while at the same time telling him what a wonderful present I thought it was. I wondered if he thought it was living. He said "no", took it from me, turned it over in his hands, and showed me a hole in the bottom. "Living things don't have holes in them like this." Did he think it looked like the snails we had been talking about? Michael looked at it carefully and said, "it's not the right colour." He also pointed out the shell that could be "squished" down and thought that it made it look like a newborn. I told him to look carefully at the eyes. This is when he noticed that the eyes were painted on the snail's face, and not on the ends of the two stalks. He laughed.

I had planned for the seasons to be reviewed using dramatization, and for Gredda Muller's book, *Circle of Seasons*, to have been read the previous week after cycles had been introduced. Instead, the lesson began with the story, and the story became a benchmark/invention lesson for many of the children rather than an elaboration (of cycles) or enlargement (thinking of the seasons as a cycle) lesson. There were so many questions about the illustrations and things said in the text that the idea of a "circle [cycle] of seasons" was essentially lost. The dramatization was very unorganized. The children counted off 1-2-3-4, 1-2-3-4… The ones were to be a plant in spring, the twos were to be a plant in summer, the threes were to be a plant in autumn, and the fours were to be a plant in winter. All but the seedlings looked the same. It became obvious that we needed props. The subtle distinctions were difficult to illustrate using stance alone. We encountered the same problem with Cathy's suggestion for a cougar, tiger, cheetah sett several weeks before.

The leaf rubbings, following a discussion of Maestro's question *Why do Leaves Change Color?*, that were to portray the seasons as a cycle, were as ineffectual as Muller's book. The children were fascinated with the process and product not representing the cycle of the seasons using light green crayons for spring, dark green crayons for summer, red, orange or yellow crayons for autumn, and brown for winter. Many of the children placed their leaves in rows on the page (using colours like blue and purple and magenta) rather than the four quadrants. In this configuration it became almost impossible to show the cycle. Those who copied the cycle onto the page that I had drawn on the board, season by season, as Muller's book was being read, didn't attempt to match the words with any particular colour. The connection between season and foliage colour had not been made, and I ended the lesson doubtful that they understood the repeating pattern that was the seasonal cycle: spring, summer, autumn, winter.

Thursday 03 October Life Cycles: Focus on the Life Cycle of Human Beings (10:40 – 11:50)

I arrived to find three words printed on the whiteboard. These were "birth," "living," and "death": the three components of an individual's lifetime. Lauren asked that I read *Lifetimes*, and this is how we began. Michael wanted to know why it was subtitled, "*A Beautiful Way to Explain Death to Children.*" Lauren answered, saying that death was one part of a lifetime that followed birth and a lot of living.

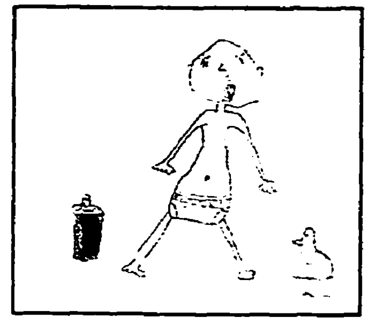
Discussion was as animated as always. When we reached the page where the Australian birds were portrayed, Danny said that he had an uncle living in Australia. I wondered if his uncle would have seen a kookaburra. Maybe Danny could ask him the next time they wrote to one another. Several children began to sing the kookaburra song.

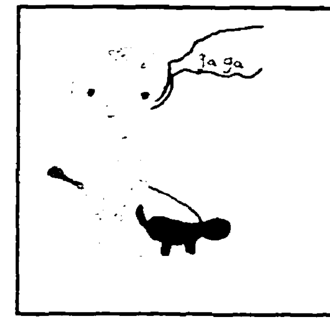
The longest discussion focused upon road kill and dead animals that the children had seen. Everyone seemed to have a story to tell. Lauren asked them to contribute something to the discussion that would fit into one of the three categories: "Is your story about birth, death, or living?" This was not easy to do. The children wanted to talk about things they had found or noticed.

At the end of the story, Lauren stood up, walked over to the white board and said, "If we are born, and we are all born, and if we die, there is a lot of living that has been done in between these two events. What happens after you're born? What kind of events are important in a lifetime?"

The children responded with comments like the following: you go to kindergarten; before kindergarten you might go to nursery school, or a day care; after nursery school you go to kindergarten; then you're in early years. At this point, Michael and several other children began reading off the timeline of Bill Peet's life on the west wall: "birth, early years, middle years, senior years, Walt Disney Studios…" Lauren talked about Peet's life in the context of the science lesson. She said that this was Bill Peet's lifetime. Not everyone would work at Disney or have the experiences he had had, but we all have a birth and we all die and we all have a lot of living in between.

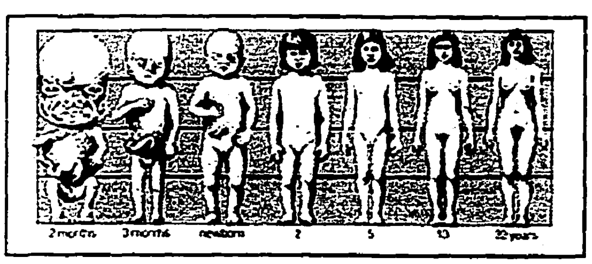
The remainder of the class was spent reading *Bigger Than a Baby* and thinking about the things that they could now do that they couldn't do as newborns and infants and talking about these changes and changes in appearance. It was their perception of themselves as babies that they would be drawing on Friday.

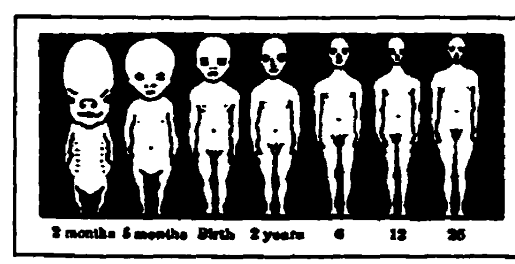




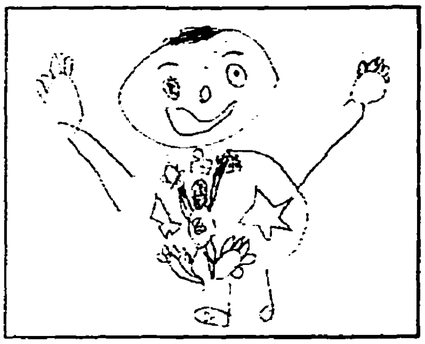
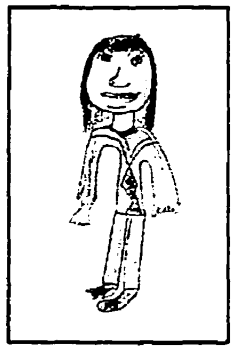
WEEK 6
Monday 07 October Life Cycles: Newborn to Early Years Student (10:40 – 12:00 NOON)

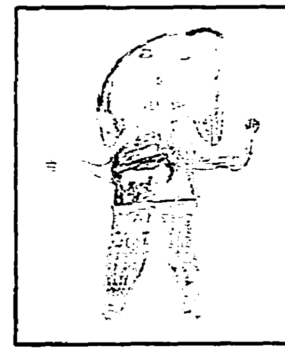
Lauren asked the children to sit around the "pumpkin patch" (a quilt made with sixteen squares in a sett that is repeated in five columns and eight rows). We began by showing the drawings they had completed of themselves as babies, naming everything that had been included, from the designer diapers, toys, and first words in dialogue balloons, to each appendage, limb, and facial feature. The first question went something like this: considering we have all of the same body parts and features today that we had as babies, how is it that we know we are seeing pictures of young children when we looks at these drawings? Just about everyone said it was size. Babies are "smaller" or "a lot smaller". Babies don't have as much hair. Ten of the drawings showed babies with teeth (Roslynn, Debbie, Anne, John, Cindy, Robert, Reena, Ken, Annie, and Cathy). This prompted several of the children to ask if babies are born with teeth. Lauren answered that she had heard of babies being born with one or two teeth in place. We both thought this was rare. In most babies, teeth don't begin to appear until they are older than three months.





The diagrams illustrating the changes in proportions of the human body during prenatal and postnatal growth generated tittering as well as questions and observations. Annie wondered why the "private areas" of the male and female had not been covered. Scott and Michael said that the head did not grow after birth. Before this question could be discussed, Annie said that her sister told her that "babies don't have brains". This was the reason we can't remember anything when we were in the mommy's tummy. Marc then said something about the skin stretching as you grow. We wondered if he thought you were born with all the skin you would need as an adult. Everyone looked at the skin on their hands and arms and legs. They didn't think it seemed very tight. Stretching seemed like a possibility. I mentioned that the skin is their largest organ. It doesn't have to stretch to fit their bigger body. It grows right along with it. Before they began the drawing of themselves as early years students, someone asked if muscles grew.



WEDNESDAY 09 OCTOBER Unscheduled Session (9:30 – 10:00)

The children in Grades 2 and 3 giggled and pointed out the baby-like antics as they watched the video, *Babies at Play on a Fun Rainy Day*. Willie, Danny, Debbie, Anne, John, and Cindy were read *Imogene's Antlers* and *Piggybook*.

This was the day the children were invited to participate in the Canadian Nature Federation's Lady Beetle Survey. An explanatory letter to the parents and the CNF Lady Beetle Survey pamphlet and reporting card were sent home with each child. Danny couldn't wait to show his mother that he was a real scientist.

Thursday 10 October School Closed (transition from temporary to newly constructed school)

WEEK 7
Monday 13 October School Closed (Thanksgiving Holiday)

Thursday 17 October Slime Survey (Science Cancelled)

Lauren was elated. When asked, all of the children said that the slime was nonliving.

WEEK 8
Monday 21 October Animals (Birds, Reptiles, Fish, Mammals) That Grow in Size With Age (10:25 – 12:10)

Lauren had read the book, *Look Out for Turtles!* on Thursday. She wanted to begin the lesson with a discussion of the turtle and turtle hatchling and the snake and snake hatchling, have the children return to their tables for the matching of the young animal with its adult parent, begin partner reading of the "See How They Grow Series", and watch the video, *See How They Grow Farm Animals*.

She called the children by table group to the reading area and sat facing them with the model of the adult turtle in her right hand and the model of the hatchling just emerging for the egg in her left hand. When the students were settled, she asked them to tell her one at a time how the two animals resembled one another and how they differed. The conversation proceeded as follows:

They both have a shell.
They are both the same colour.
They both have legs.
They both have a bridge (that portion of the shell that connects the upper shell - carapace to the lower shell - plastron). No one could remember the exact word for this part of the tortoise, so Michael got the book, *Look Out For Turtles!* and they looked it up.
They both have a head.
They both have a mouth.
They both have four legs.
Scott said that a turtle only had two flippers. It also has two feet. Several weren't sure that Scott was correct. They knew that a sea turtle had flippers in the front, but they weren't sure it also had flippers in the back. Lauren opened the book to the illustration of the sea turtle. It was obvious that the artist had given the turtle four flippers but the children weren't convinced. I thought that the tortoise and the turtle probably had the same number of bones in the skeleton of their hands and legs, but that through time as the turtle left the sea for land it didn't need flippers. So the flippers were lost in favor of feet.
Someone wondered if a turtle with flippers could walk on the land. Someone remembered that the turtle laid its eggs in the sand of a beach, so it had to be able to walk on the land. It used its flippers to push its body across the sand. They would certainly be more useful in the water.
Lauren wondered what scientists called the eggs laid by a single turtle.
Marc remembered that it was a "clutch."
Lauren asked how the baby turtle managed to get out of the egg.
Someone said they used a special egg tooth.
Willie mentioned that there was a turtle in Robin Hood. It was a little turtle. (He must have been thinking of Disney's animated version).
At this point someone (a girl) said that they both (the hatchling and the adult tortoise) began in an egg.
Lauren wondered out loud, "Is this right. Did the adult tortoise also begin life in an egg as a hatchling?"
Most of the children nodded in the affirmative. Several didn't respond.
Lauren continued. "Did this tortoise (adult) look just like the baby (hatchling)?
There was a chorus of "Yes."
Lauren asked me to pick up, and hold, the adult and "hatchling" snakes. She asked, "Could the turtle have laid the egg the snake is coming out of?"
There were several giggles. "A turtle couldn't have a snake baby."
Could the snake have laid the egg the turtle emerged from?
Again there was laughter and giggles.

Lauren persisted. How would you tell a small child, who doesn't know as much as you do about animals and their babies, that the young snake does not belong to the adult turtle and that the young turtle does not belong with the adult snake.
This seemed to be confusing to the children.
Someone said, the snakes don't have shells like the turtle.
The snakes don't have legs.
They are different colours.
The snake is bigger. (It was the model that was much larger than the model of the tortoise.)
Snakes slither. Turtles walk slowly.
The snake is slimy and slithery. The turtle has a hard shell.
Snakes have scales. Turtles don't.
She again asked how they would explain to much younger children why the hatchling turtle belongs to the adult turtle and why the hatchling snake belongs to the adult snake.
We went through similar criteria.
One has legs, one doesn't.
One has a shell, the other doesn't.
One is brownish, the other is greenish.
One has a tail, the other doesn't.
Lauren asked, "Scott, which of these two animals doesn't have a tail?"
The turtle.
But the turtle has a tail. Lauren points it out to him.
Well the snake has a much longer tail.
Lauren asks me to summarize everything. I said that when an animal gives birth to another animal, if that animal is a bird or a fish or a reptile or a mammal, the newborn will always resemble the parent. It may be smaller, but it will have the same physical appearance. So the snake will lay an egg and the animal that hatches out of that egg will look like a smaller version of the parent snake. It will never look like a turtle or a any animal other than the snake itself. The same holds true for the turtle. It will lay an egg, and the animal that hatches out of the egg will never be a snake or an alligator. It will always be a turtle that looks like a small version of the adult parent.

Lauren takes me aside and suggests that we spend time on animal classification.

Thursday 24 October Animals That Change Form and Structure as They Age (Newborns Do Not Resemble Adults) - Focus on Amphibians (10:40 – 11:55)

The lessons began with a review before the life cycle of the frog was discussed and before Chinery's book, *Frog*, was read by a teacher substituting for Lauren. What could they tell me about the animal that hatches from a turtle egg and the animal that hatches from the egg of a snake? They thought for a few seconds and then mentioned that snakes can only have snakes and that turtles can't make eggs that have anything but turtles in them. Marc said that the babies of snakes always look like their parents, and that the babies of turtles always look like their parents. Cathy said that a turtle can't have a baby that looks like a snake, and a snake can't have a baby the looks like a turtle. All of the children agreed with Cathy and Marc when they were asked if this is what they believed.

As *Frog* was being read to the children, several asked when lunch would be. There was just enough time before clean-up to watch the segment on the frog from the *See How They Grow: Pond Animals*. Everyone is now singing along with the chorus that starts each of the animal sequences in this series of videos.

WEEK 9
Monday 28 October Review Animals That At Birth Resemble Their Parents and Introduce The Insects (10:45 – 12:00 NOON)

We begin with the children in a circle on the floor and asked them, in order, to name an animal that gives birth to a baby that resembles the parent. (The circle began at my left with Neil, Peter, Danny, Scott, Marc, Patrick, Michael, Sam, Ken, Robert, Willie, Debbie, Sara, Reena, Annie, Quinn, Cathy, John, Cindy and Anne.)

They were asked to think of an animal that no one else would mention so at the end of the activity we would have the names of 20 different animals. Lauren asked if there were any questions. Reena wondered what the word "resembles" meant. I answered, "looks like." Michael wondered if they could make the sound their animal makes. We thought this would be a good idea, if there was time.

This is the list as it was written on the white board:

whale	zebra	bear
rattlesnake	giraffe	duck
white German Shepherd dog	monkey	rabbit
cat	cow	dolphin
pig	tortoise	alligator
horse	shark	chicken
gorilla	penguin	lamb

Off to the side was the word, "ladybug" suggested by Reena. Since we hadn't studied the insects, she wouldn't have know that few insects are born resembling their adult parents.

As the children named an animal, they were asked, "How do you know that a baby _______ (name of the animal suggested) resembles its parent?" Most replied: "I saw it on a TV show" or "I saw it in a book" or "I saw it at the zoo".

Disagreement and uncertainty came with the calf, the duckling and the rabbit. The baby calf was often a different colour from the mother cow, and it could be a bull (a boy). The duckling, Peter thought, could grow up to become a swan, and a swan doesn't look like a duck. Also the ducklings "hair" was yellow, not white and it was softer. Several children said that the rabbit didn't look like the mother because it was born without hair, and it could be a different colour.

The cow was the first to be questioned. Lauren deferred to Robert because his father raises dairy cows. Robert agreed that both colour and gender could be different. We wondered if colour was an important feature to focus upon. When we think of the cow, think of its body or physical structure. Does the calf have the same physical structures (body parts) as the adult cow does? The students seemed to agree that it does.

Then we came to the duckling. Many students felt that it didn't resemble the adult parent. I asked Lauren if she could get the "See How They Grow" books from Cecile's classroom. When she came back, we looked at the pictures of the duckling as it grew over a six week period. We noticed that the feathers were down-like, and that they were a different colour compared to the adult. But, the ducking and the duck both had a head with two eyes and a bill, a neck, a body, wings, two legs and webbed feet. They had the same body parts. Scott wondered if they both had the same parts inside their bodies. He wanted to say that they differed in one respect, but didn't want to say where – "it was a private part". Lauren asked him to whisper it in her ear. It had something to do with the elimination of body waste, because Lauren said that it was all right to speak of this part. The adult duck had to have an organ to get rid of waste material, did they think the duckling needed a similar organ. The students all agreed that the duckling needed this organ as much as the adult.

The next problem was with the rabbit. Again we had to look at the "See How They Grow" book on rabbits. It is true that the kit is born without hair, but when the features of the adult rabbit were listed and the children were asked if these same organs and appendages could be found on the baby rabbit, they agreed that they had the same body parts.

Thursday 31 October Science Canceled (Early Years Halloween Party)

WEEK 10
Monday 04 November Insects with Gradual/Incomplete Life Cycles: Egg - Nymph - Adult (10:40 – 12:00 NOON)

When everyone was settled, Lauren said that the children had just learned a cycle - the cycle of the months of the year. She asked Reena if she could recite them for me. Reena did this task, slowly and carefully, without one mistake. Lauren thanked Reena, stood up, and said that today they would not be studying the life cycles of mammals, or reptiles, or birds, or fish, or amphibians, but the life cycles of insects. These were special insects that hatched out of their eggs as nymphs and then became adults. What insects did this include? The children began saying with her "grasshoppers, crickets, dragonflies, damselflies, praying mantids, and giant water bugs". I was very surprised because I hadn't introduced these insects to them (Lauren obviously had).

I wondered how they knew of all these different insects. How many (show of hands) had ever seen a grasshopper? A cricket? A dragonfly? A damselfly? A praying mantis? Lauren kept count. All of the children had seen grasshoppers and crickets, most had seen dragonflies, quite a few had seen damselflies, but less than half had seen a praying mantis.

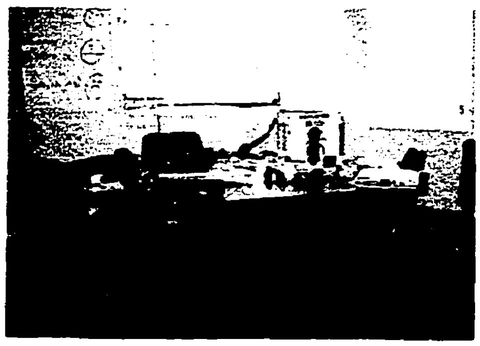
Had they heard the crickets in the terrarium? We talked about the grasshopper and the cricket and how they make the sounds they do. Both are only capable of producing sounds when they molt for the final time and become adult insects. This is because they use their adult wings in the case of the cricket and their adult wings and a knob on the jumping legs in the case of the grasshopper. If we hadn't heard the crickets chirping, what does this tell us about the crickets in the terrarium? Several children said that they must still be nymphs.

Marc said that he knew that grasshoppers could jump six times their body length. I wondered where he had learned this. He said that he had a book at home about insects and that was one of the things he had read. We got into a discussion about the difference between hopping and jumping. Was the grasshopper jumping or hopping? What did it mean to jump, Lauren wondered. Was there a difference between jumping and hopping? Scott suggested that frogs jumped. Marc said that grasshoppers must hop because that would be why they have the name we call them, grassHOPpers.

Patrick demonstrated what he believed a jump and hop must be. If you jumped, your feet went off the floor, but you came back down in the same place on the floor where you began. If you hopped, you went up and covered a distance. So you didn't land in the same place that you had begun. Lauren asked the children to take one hop like the grasshopper. They were to notice the place at which they set off and then compare the distance they had moved from this starting point. Did they think they could jump like the grasshopper and travel a distance six times their body length? Most of the children thought not. Michael became the standard. Five, not six body lengths, were all that could be fit along the available length of the classroom. Most of the children could not hop further than Michael was tall. Patrick was certain that if he could take a running start, he could hop two body lengths.

After discussing the life cycle of the dragonfly and what it means for an insect to molt, the children reenacted the life history of the grasshopper. This began with the egg and the nymph that emerged that would eat and grow and become too big for its exoskeleton and molt, and eat and grow and molt, and eat and grow and molt until emerging as the adult with wings. I became the bird who preyed upon the grasshopper emerging from its exoskeleton when its body was soft and had not had time enough to harden. Several of the children believed that they could escape by flying. Does a grasshopper fly or merely use its wings after hopping to stay aloft longer than it might otherwise?

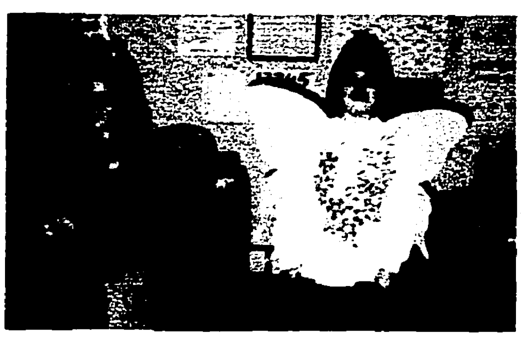
Annie and I discovered two exoskeletons in the terrarium when we added an apple core and a piece of her carrot. What did this mean? "Two of the crickets had molted. They should look bigger. Their wings should be bigger."

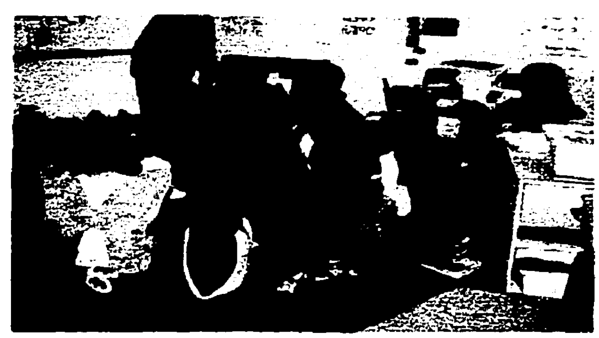


Thursday 07 November School Closed (Snow Day)

WEEK 11
Monday 11 November School Closed (Remembrance Day)
Thursday 14 November Science Cancelled (Student Led Conferences)

WEEK 12
Monday 18 November School Closed (Snow Day)
Thursday 21 November Insects with Four Stages in Their Life Cycles: Egg - Larva - Pupa - Adult (10:40 – 12:10)

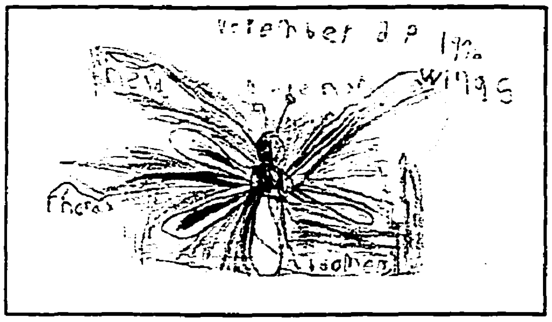


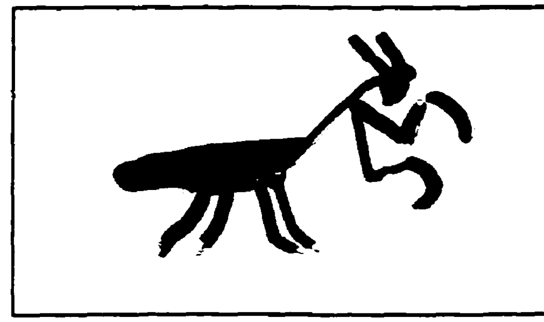


At the end of the story of the hickory horned devil caterpillars from *Insect Metamorphosis* by the Goors and the dramatization of the life cycle of a butterfly, I shared the answer to a question that had been asked more than two weeks ago. The question was, "How many insects are there?" I showed them an article in Scientific American that talked about the number of species in the world. There were approximately 800,000 species or kinds of insects.

This was more than all of the green plants in the world, all of the fish, all of the birds, all of the mammals, and so on. Several children wondered how they had counted them all. It was not 800,000 insects, I said, but kinds of insects. If we think about mammals, human beings are one kind of mammal even though there were approximately 5,000,000,000 of us on Earth. Similarly, there could be 5,000,000,000 of just one kind of beetle or one kind of moth or one kind of praying mantid. Scientists knew about and had classified 800,000 kinds of insects. This represents millions, tens of millions, hundreds of millions of insects.

I then shared a newspaper article that my mother had sent about frogs in North America. It said that students on a field trip had found frogs with one back leg or four back legs where there should have been two. Initially researchers believed that some form of pollution must be causing these deformities. Maybe there was another reason/explanation. I showed a recent article from the Globe and Mail's science page that told of a California researcher who attributed the deformities to a fluke (a flatworm) whose life cycle depended upon the garter snake, the snail, and the frog. I told them that the snake deposited its waste in wetlands and that this waste contained the eggs of a flatworm that lived in the snake's intestine. These eggs were gobbled up by an animal that we had studied at the beginning of the unit. Marc, called out "snail." Yes. The snail ate the eggs and instead of the eggs hatching and freeing one fluke, one egg might give rise to hundreds of flukes. These flukes were free swimming and parasitic on tadpoles/frogs. Instead of hunting for food, they would attach themselves to a tadpole, burrow inside the tadpole and feed off the tadpole. How did they think the fluke got inside the tadpole's body? If we think about the tadpole before it became legged, where did they think the softest tissue might be. Marc again answered, saying the legs, or where the legs would eventually come out. This was correct. Did they remember the favorite food of a garter snake? "A frog" everyone called out. Yes. The scientist, written about in the article, believed that the deformity occurred in frogs that were not eaten by snakes as tadpoles. The flukes in the frog's body did not allow the legs and other developing parts to mature properly. This, he believed, was the cause of the deformities that had been observed all over North America, not chemical pollutants. I concluded by mentioning the Friends of the Frogs home page (from the Minneapolis column).They might want to look at it the next time they were on the internet.





Friday 22 November Presentation of Insects (Living, Pinned, Preserved, and Photographed) by Tanja McKay and Carla Wytrykush of the Department of Entomology, University of Manitoba (10:40 – 12:10)

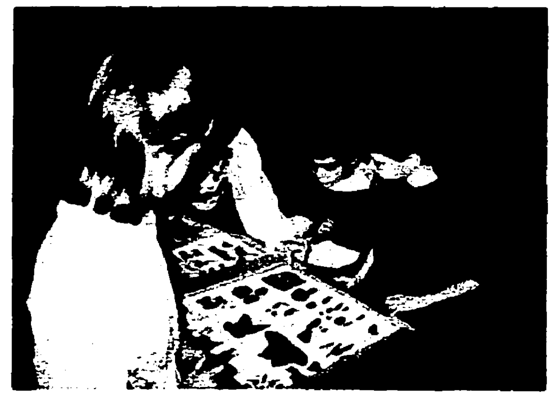
(For an annotated list of the slides shown see Appendix E)

At the end of the slide presentation, the children were asked to look at the pinned insects on display, the photographic reproductions of insects, and to line up to view the meal worm pupa under the dissecting microscope and the house flies in the Plexiglas box. The children spoke with one another and with Tanja about the pinned insects. They were amazed to see so many different kinds of insects. They wanted to know why some (like the termites) were in solutions in small glass bottles. Was one of the beetles really a rhinoceros beetle? They were surprised to see the scale of the praying mantids and the large tropical cockroach. Near the drawer that held the beetles, several of the children in Lauren's classroom including Cathy and Sam said that they could tell which ones were the adult beetles and which ones were the babies. Knowing that beetle larvae don't look anything like the adults they will become, I asked them to show me how they could tell the "babies" from the adults. That's simple, Cathy said. "The babies are the littler ones and the adults are the bigger ones."

At 11:55 Lauren asked the children to take a seat on the floor. She gave them the opportunity to ask questions. Most of the questions are given below.

- Why do you want to be a scientist?
- How do you get them all?
- Do you know all the names of the bugs?
- (Sara) Once my brother got bit by a fly. [Was it like the flies in the Plexiglas box?] It was a horse fly, not a house fly.
- Once I saw a bee hive in the woods.
- How many bugs do you have?
- (Annie) Where is your school?
- How did you get interested in bugs?
- (Willie) How come you have bumble bees in this drawer?
- How many house flies are in the box?

- (Debbie) Where did you get all of those pretty butterflies?
- How do you feed the house flies in that box?
- How many bugs did you bring here?
- How many different kinds of bugs did you bring?
- (Michael) How many boxes do you have of those bugs?
- (Sara) How many can you get into one box?
- (Debbie) How do you capture dangerous bugs?
- (Michael) Why do you put pins through the bugs?



WEEK 13
Monday 25 November Insects with Four Stages in Their Life Cycles: Egg - Larva - Pupa - Adult (10:40 – 12:05)

We discussed the life cycle of the honey bee. The children flew over to the sink as worker bees in preparation for lunch. Marc stopped me and said, "I don't want to be a worker bee. I want to be a drone."

Thursday 29 November Insects with Four Stages in Their Life Cycles: Egg - Larva - Pupa - Adult (10:40 – 12:05)

Annie brought in her book about insects. After reading about *Two Bad Ants* and discussing the life cycle of an ant, we looked at the pictures in her book of ants and termites and bees. The pages on ants asked the question, "What do ants use their feelers for?" Annie read this heading. I asked the children what another word for feelers might be. They said antennae. We asked the children the question posed by the authors of the text. They thought that they might use them to get by one another in their underground tunnels. To tell one another where they might find food. To say hello. Annie read out the explanations given in the text. She said that the pictures really gave it away.

WEEK 14
Monday 02 December **Insects with Four Stages in Their Life Cycles: Egg - Larva - Pupa - Adult** (10:40 – 11:55)

We began with the life cycle of the mosquito, then reenacted its life history in dramatic play. When they arrived at the pupa state, Lauren wondered what changes might be occurring to the larva. Someone said, it gets wings. Another said, it gets three pairs of legs. Willie said, it gets jaws. Certainly the mouth parts changed (I wasn't certain about an external jaw). Michael said that it gets a head, thorax and abdomen. I wondered if it didn't have a head and thorax and abdomen as a larva. Does an insect only have three body parts as an adult?

Lauren asked the children to stand and count silently by 2s to 100. This was the time they had to allow for their wings to dry. When they had counted to 100, they could fly out into the open space and back again as the adult mosquito. When they had returned, I asked if they knew how the mosquito made its high pitched buzz. Did it make sounds through its mouth like we make sounds? One of the students said that it was the mosquito's wings flapping. Yes. They beat their wings so rapidly that it makes the air vibrate around them. Could they name another insect that made a sound with its wings. "A cricket" was the response.

During this lesson, there were many questions posed by the children and many bits of information offered. Cathy said that she was allergic to insect bites. Lauren wondered what happened when she was bitten by a mosquito. What did it mean to be allergic? Cathy said that she gets big bumps. Lauren said that the bumps can be as large as a dime and sometimes as large as a nickel on people who are bitten by mosquitoes. One of the students thought that it was the mosquito taking blood that made the bump and itching feeling. The adult mouth parts are a lot like a straw. In order for the mosquito to get blood up the straw, it first had to put a chemical that its body makes into the animal being bitten. This stops the blood from getting thick like a milkshake and makes it a lot easier for the mosquito. It is this chemical that makes our skin feel itchy where the mosquito bite occurred.

Some of the questions asked by the children follow:

- How big can a mosquito get? Robert answered, saying that he had once seen a mosquito about a millimeter in length in his barn. Lauren asked the children to look at their thumbs, and said that one millimeter would be about as long as their thumb nail.
- Sara wondered how far a mosquito could fly without resting.
- Scott wondered how fast a mosquito could fly since a dragon fly could go as fast as 95 km/h.
- Michael wondered if it was good for mosquitoes to bite us after I mentioned to the children that it is only the female mosquito that bites animals as she needs the blood to make her eggs. I asked him what he thought. He said that if mosquitoes did not have us to bite, they would not be able to continue their life cycle since the female needed the blood for her eggs. I asked

him if there were other animals with blood that mosquitoes could use instead of us. He nodded in the affirmative. It's just a lot easier to get blood from us because we don't have as much hair covering our bodies as horses and cows and sheep do.

- Annie said that mosquitoes bite horses and that horse flies bother them too. She was right, but did she know that the flies bite rather than inserting a mouth part to remove blood. Their bite would be a lot more painful. Lauren wondered if horse flies bite humans. Annie said that they do.
- Cindy wondered how long mosquitoes could stay awake. Do they stay up all day long?
- Marc and Willie both talked about mosquitoes being out in the evening and at night. Marc said that mosquitoes don't like the daylight. So they are most active at night.
- Debbie mentioned the time a mosquito larva crawled up her leg. She was frightened of it because of the way that it looked.
- Ken thought that the larva of the mosquito was like a scorpion. It must be the breathing tubes, or is it the shape? Lauren said that the more he knows about mosquitoes and the more he knows about scorpions the more he will recognize that they really aren't the same.

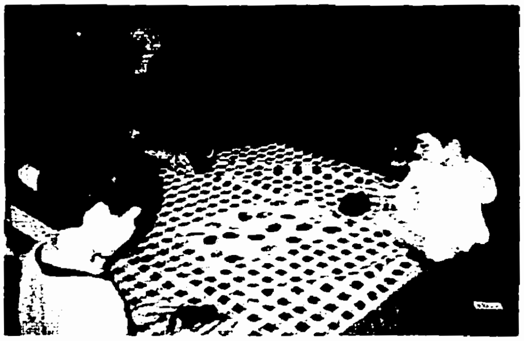
The lady beetle was introduced with a story, and the story generated many questions. Some of these follow:

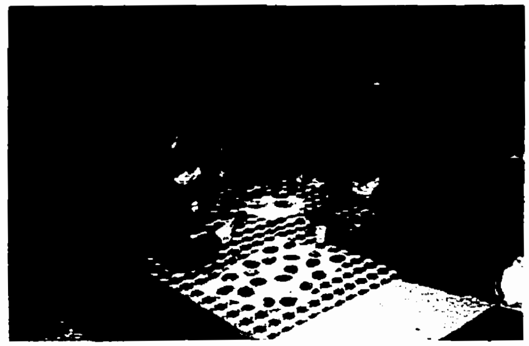
- What is a thermal current?
- How far could a ladybug travel without resting?
- Could we make kites?
- What would happen to the ladybugs put in the sacks [to sell to farmers interested in biological controls]?
- How long could they live [in the sacks]?
- What do they do in the winter?
- Where are its wings? This question prompted Willie to start talking about his experience with ladybugs. He stood up to tell us about the time he walked into his yard and all sorts of ladybugs with their "beautiful hard wings and little thin wings" flew up and around him. As he spoke he used his arms and hands to show us the way they had flown in the air surrounding him.

In the discussions, it became evident that many of the children believed that the number of spots on the ladybug increased with age. We looked again at its life cycle. It emerged from the pupa as an adult. If four spots eventually appeared on its hard wing covers, would it die with eight or ten or fourteen? Marc said "no" but many still weren't sure.

Thursday 05 December Making Ladybug Paperweights out of Clay
Friday 06 December Post-instruction Interviews
13:07 – 13:42 Debbie
13:45 – 14:12 Annie
14:15 – 14:40 Sara
14:42 – 15:08 Anne

WEEK 15
Monday 09 December Making Ladybug Christmas Cards and Post-instruction Interviews
09:20 – 09:50 Ken
09:55 – 10:25 Michael





Tuesday 10 December Painting Ladybug Paperweights and Post-instruction Interviews

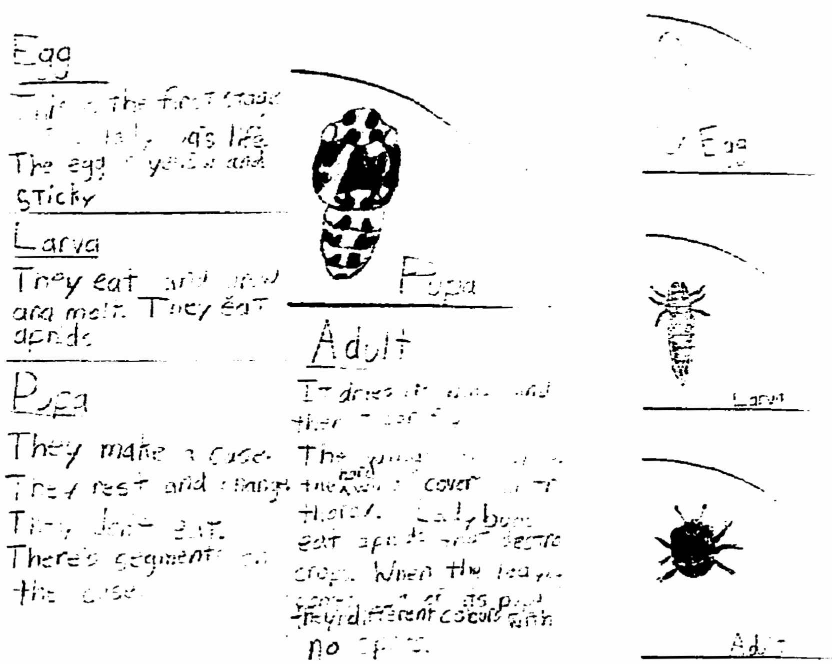
09:10 – 09:40 Cathy
10:18 – 10:43 John

Wednesday 11 December Post-instruction Interviews

09:10 – 09:42 Danny
09:45 – 10:14 Marc
10:17 – 10:53 Cindy
11:15 – 11:43 Reena

Thursday 12 December Writing for Christmas Cards and Post-instruction Interviews

09:20 – 09:55 Willie
09:58 – 10:30 Scott



WEEK 16

Monday 16 December Post-instruction Interviews

10:20 – 11:05 Robert

CHILDREN'S RESPONSES TO THE POST-INSTRUCTION INTERVIEW

Fourteen of the seventeen children in the study were interviewed at the conclusion of the unit. Roslynn (Grade 1), who would not permit the recording of my questions or her responses during the pre-instruction interview and Patrick (Grade 3) who missed the pre-instruction interview were not asked to participate in a final interview. Robert (Grade 2) was interviewed, but the audio recorder failed to record any sounds onto the tape. As a result, the data represent the responses of fourteen children whose interviews were audio recorded and transcribed.

DATA FROM QUESTION 1

1. If you had to describe this object (a red potato tuber) to someone who had never seen it before, what would you say about it? If the name is not given in the description, ask: "What do you think it is?"

   Where would you look to find potatoes? If the child answers, "In a garden", ask: "Where is this part of the potato (the tuber) found in the garden? Is it on the ground or hanging on the plant or in the earth?"

   Would you say that this potato is living or nonliving? Why do you think so? If a child in answering any of the preceding questions has already said that it is living or nonliving, ask the following:

   Let's say you were a scientist from another planet and had never seen a potato or potato plant before, but you knew about plants because different plants grew on your planet. Now if you happened to come to Earth, and couldn't speak English, and saw this (potato), what would you do to figure out whether or not it was living or non living? What kind of questions do you think a scientist would ask to determine if this object (potato) is alive or was once alive?

With the exception of Reena who called the red potato tuber a tomato, the children correctly identified as "a potato" the object that they had been asked to describe. The descriptions varied in the details stated as the following excerpts reveal:

> "Um-m-m. It has little [three second pause] dots. Little holes, kind of things [six second pause]. It's a potato because my mom planted those last week. I. In this week. Yep. And I plant. And I help plant. I help plant the potatoes with my mom." (Willie)
>
> "Ah-h-h. It grows in a field." (Debbie).
>
> "...my mom peels them." (Anne)

"That it's a [two second pause] potato, and you have to eat it. You slice it. An-n-d. You have to-o. It's something [two second pause] And it also has red where you have to peel off, of course. An-n-d. Hum. There's a lot of dots on the red. That's it." (Cindy)

"It has some holes in it. It has some wrinkles on it, like these things here [points to indentations]. It's in a like an oval shape. And it has this bump right here, and it has this little [inaudible] and this line. Ah-h. There is peel coming off here." (Scott)

"Um-m. You can cut it up, and you can eat it. You can mash it. You can um put some catsup on it and eat it for supper." (Reena)

"Um-m-m. It [two second pause] like [two second pause] grows underground, and [three second pause]. Oh-h-h. You [two second pause] eat it. And [three second pause] bugs grow on it." (Ken)

"Um [three second pause]. That it's kind of pink, and you can eat it." (Annie)

"It's a vegetable. Um-m [two second pause]. It used to be living. Ah-h [three second pause]. You can eat it. It grows under the ground. Um-m [eight second pause]." (Marc)

"Um-m. It's a potato. You make fries out of it. Um. Um. It's smooth. You get it out of the ground. Um. That's it." (Cathy)

"It's red. It has a lot of eyes. Ah. Um. It's a potato [laughs]." (Michael)

In response to the question, "Where would you look to find potatoes?" seven children suggested looking "in a garden" (Cindy, Sara, and Annie), "in the garden" (Anne, John), "in your garden" (Danny) , or "in our garden" (Michael). Debbie answered, "It grows in a field." Reena said, "...the Safeway or the market. At the fruits um, um row. Column [aisle]!" Scott responded, "In my garden or at the store."

Ken and Marc in their descriptions of the potato had said that it grows "underground" and "in the ground", respectively. Cathy's description mentioned getting a potato "out of the gound." When asked where the potato (tuber) itself would be, "Is it on the ground like a pumpkin or up in the plant like a bean or in the earth like a carrot?" Scott answered, "Ah-h-h. Above the earth." Reena replied, "Um. It rests on the ground." Anne and Sara had never seen a potato growing. Ann responded to the question with silence. Sarah answered, "It's in the earth." Debbie didn't know anything about how the potato grows or what it would look like as it grew. She said, "We. Cause we have a field back here and it, it grows sunflower seeds, not potatoes." Danny and Cindy responded, "under the ground." John and Sara replied, "in the earth." Annie answered, "in the soil." Michael said, "underground" and then added: "It would be in the earth and part might be sticking up." Willie's response is given in the excerpt below:

> McMillan: When you look at the potato plant, where is this part of the potato? Is it above the ground or hanging on the plant or in the earth?
>
> Willie: Um [two second pause]. It's hanging underground.
>
> McMillan: Can you see it when you look in your garden?
>
> Willie: No. Cause if it. Cause if it was on, on top of the ground, then they won't be good to eat.
>
> McMillan: Oh. I didn't know that. Why? What happens to them?
>
> Willie: They get rotten. And. And. And we can't eat them. Cause then they would get rotten, and they would taste yucky if you ate them.

Twelve of the fourteen children responding to the living-nonliving questions believed that a potato (tuber) was nonliving. Eleven of these twelve said that a potato plant growing in a garden would be living. Sara didn't answer the question about the plant. She didn't think the scientist from another planet would know, just by looking, if the potato plant was living. When asked why, she responded, "Because if people are from a different planet, they wouldn't know what it is, because they're from a different planet. They don't know the same things as you do."

Of the eleven children who said the potato plant was living, ten attributed this to a requirement for food, water, and air. Like Michael quoted here, they believed "all living things need food, water, and air." When Debbie was asked, "Does this potato need food, water, and air?", she responded: "Hum-em. Cause it only needs water and air to grow. Like, we need food, water, and air." In addition to food, water and air, Cathy mentioned that a plant "needs sunshine." John said a plant won't grow very well without "the roots."

The potato tuber was thought to be nonliving for several reasons. Reena said, "It's like a rock, but it's nonliving." When asked how she knew that it was nonliving, she responded:

"Because um if it were living it would move, and it would need food, water, and air. And if it was nonliving, it would just sit there." At this point she was asked to look at a potted Philodendron plant hanging from the ceiling near a set of windows. The interview progressed as follows:

> McMillan: Is it [the potted plant] moving?
>
> Reena: No
>
> McMillan: Is it living?
>
> Reena [Whispers] Yeah.
>
> McMillan Why? How do you know?
>
> Reena: Because it needs food, water, and air.
>
> McMillan: Do you think that when this [the potato tuber] was attached to the plant that it was living?
>
> Reena: Yeah.
>
> McMillan: So when did it become nonliving?
>
> Reena: When the farmer went to go pick them it was summertime, and he just went like this [makes a cutting motion]. And then it would be nonliving cause it was attached to the vine and into the ground where the root was.

Cindy, like Reena, also used motion as a criterion for living. When asked, "How would you find out [if the potato tuber was living or nonliving]?" she said: "Cause [two second pause]. Anyways [three second pause]. I'd just put it down, and if it's not living. I am touching it, it's just moving because of my finger. And I know that's not living." Her responses to the questions similar to those asked of Reena are given below:

> McMillan: Just because it can't move?
>
> Cindy: Yeah. Like when I'm not touching it.
>
> McMillan: Ok. But look at the plant up there. Now, is that living?
>
> Cindy. Yeah.
>
> McMillan: Is it moving?

Cindy. No. It moves from the wind, and it needs water and [two second pause] and [two second pause]. Um. Food, water, and air.

McMillan: So do you think this potato [tuber]does [need water, food, and air]?

Cindy: Well, in the ground, yes.

McMillan. Ok. But once the farmer or gardener cuts it away from the plant it's growing from, does it need food, water, and air anymore?

Cindy: No.

McMillan: So would you tell that person who came from another planet that this [potato tuber] was nonliving?

Cindy: It is n-n-. Well it was living when it was in, under the garden place, and [two second pause] but there was this person who just took it out, and then it didn't [two second pause] it wasn't a real thing.

McMillan: Ok. So if I were to put that in the ground when spring comes, what do you think would happen to it?

Cindy: Um-m-m. Get rotten.

Marc also believed a re-planted potato tuber would rot in the soil. Reena said, "It would still be nonliving, but it might [five second pause] um-m-m-m [three second pause] just stay in there.

Of the twelve children who said the potato tuber was nonliving, Ken is the only one who began by saying, "It looks like it's never been alive." When asked what he might do to find out if it had never been alive or if it had once been alive, he responded: "Ah-h-h. Eat it or something?" The interview continued as follows:

McMillan: Ok. But if you ate a piece of bread, would that help you know if it was ever alive?

Ken: No-o-o [laughs].

McMillan: No. So what kinds of things do you think a scientist would ask if he found something that he had never seen before?

Ken: Ah-h-h [three second pause]. Is it living or not?

McMillan: And how would he know?

Ken: Ah-h. I don't know.

McMillan: What things do we need to stay alive or do plants need to stay alive?
Ken: Ah-h [three second pause]. Food, water, and air.

McMillan: Ok. So do you think this needs any of those things?

Ken Ah-h-h [three second pause]. Yeah.

McMillan: You said the potato would be underground. Would it need food, water, and air?

Ken: Yeah.

McMillan: So do you think that once it has been harvested and taken away from the plant that it is alive or is it nonliving?

Ken: Um-m-m. Nonliving.

McMillan. Ok. And why do you think that?

Ken: Ah-h-h. Because it's all rusty all over.

McMillan: Because of what?

Ken: It's all rusty and stuff.

Debbie, Anne, John, Scott, Sara, Annie, Marc, Cathy, and Michael all believed that the potato tuber was living when attached to the mother plant, but in their hands as a solitary potato tuber it was nonliving. The explanations given were like those of Cindy, Debbie, and Scott reported here:

"Because it's off the vine and doesn't need food, water, or air" (Cathy);

"Because it got pulled up" and no longer "had the roots" or was "growing" (Debbie);

"Because it got pulled from the thing that it got feeded by… because it needs food, water, and air to live. Because it needs air to breath. It needs food um [two second pause] live, also [two second pause] whatever that, energy, wouldn't be able to move. And the water so it, so your mouth doesn't dry up or anything" (Scott);

Danny and Willie, in contrast to the children above, answered that both the potato and the potato plant were living. Their responses to the interview questions are presented below.

McMillan: Now if you were a man from another planet, and you had never seen a potato growing and had never seen a potato like this, and you came to Earth, and you saw people with potatoes, how would you decide whether or not a potato was a living or a nonliving object?

Danny: Um. You would check if it needs air.

McMillan: And do you think this needs air?

Danny: No.

McMillan: And what else did you say you would check to see?

Danny: If it needs food.

McMillan: Do you think the potato needs food?

Danny: No.

McMillan: So, if you were that alien person, would you think the potato was living or nonliving?

Danny: Living.

McMillan: Ok. If you saw the plant growing would you think that it was living or nonliving.

Danny: Living.

McMillan: When the potato was harvested by the gardener or farmer, would this part still be living even though it has been separated from the plant?

Danny: Ah. Yeah.

McMillan: How would you know that?

Danny: It will need. It will need water.

McMillan: Does it need water? When you buy potatoes from the store do you keep them in water or give them water?

Danny: No.

McMillan: So how would that person from a different planet decide if this was like a rock that had never been alive or was like something that had been alive?

Danny: He would check if it needs food and air?

McMillan: Ok. Alright.

Willie is the child who planted potatoes with his mother. When asked how this was done, he replied: "Um-m-m, if there's roots on it then we plant it with the roots sticking up." This led to the conversation about above ground tubers rotting and tasting yucky, and then to the exchange presented in the following excerpt :

> McMillan: Ok. Well, what I am wondering is, do you think that potato is living or nonliving?
>
> Willie: Um-m. Living.
>
> McMillan: How do you know that Willie?
>
> Willie: Because it feels like a real potato.
>
> McMillan: Ok. Now just imagine that you are a boy from another planet and you were coming to earth and you had never seen a potato before and you saw this and you thought, "Oh boy! That really looks like a rock. I wonder if it's alive." Now what kinds of question would you ask to find out whether or not it was living or if it had never been alive?
>
> Willie: Um-m. Is this living or non living?
>
> McMillan: And how would you know?
>
> Willie: Cause. Cause that. Cause that would help me know what it, it, it would be, like, where it is.
>
> McMillan: Ok. And what kinds of things do living plants and animals need?
>
> Willie: Ah-h, um-m. Food, water, and air.
>
> McMillan: And do you think this potato needs food, water and air?
>
> Willie: Yeah.
>
> McMillan: Does it, even when it has been harvested and taken away from the plant?
>
> Willie: Yeah.
>
> McMillan: So does your mom give her potatoes that you have in your house food, water, and air?
>
> Willie: No. It just gets. It gets air and water to make it grow.
>
> McMillan: Do you think it's growing right now?
>
> Willie: [Chuckles] No.

McMillan: But if you were to put it into the ground, what do you think would happen to it?

Willie: It would grow from the plant.

DATA FROM QUESTION 2

2. Ask the child to name the animals in the order they are arranged on the tabletop. If s/he does not spontaneously mention that they are arranged in a pattern, ask: What can you tell me about this arrangement of animals? If the child says that that animals are arranged in a pattern, ask: What is the pattern that you see? Can you show me the sett? How many times has the sett been repeated to make the pattern? Can you continue the pattern with these pieces?

   What could you do to make this pattern into a cycle? Can you show me, and as you make a cycle can you tell me what you are doing to make the pattern a cycle? (What is a cycle? How does it differ from a pattern?)

Twelve of the fourteen children said that the twenty animal models had been arranged in a pattern. Two of the twelve responses, one from Cindy and the other from Scott, were unsolicited. Cindy and Scott began by attempting to name the animals placed on the tabletop. Both recognized in the naming of those in the second sett that there was something special about the way they had been positioned. Cindy said: "Hippopotamus. Lizards. And all over again! This looks like. I know what this is: A pattern!" Scott's response was: "Hippopotamus. Lizard. Um. I think it's a pattern. Because um. Because um, it starts with a hippopotamus, and it goes lizard, And here's a hippopotamus and there's a hippopotamus here. And lizard and lizard, beetle and a beetle, and two of these and two of these, and one of these and one of these, and so it goes [as he speaks, Scott uses his fingers to point out an animal or two animals in one sett and their compliment in the second sett]."

A third unsolicited, but inaccurate, response was offered by Annie. When asked to name the animals the models represented, she responded: "A rhinoceros. Lizards. Um-m, a beetle. Octopuses, and um-m-m-m. A rhinoceros beetle? And bees. Another rhinoceros. Then a lizard. Another beetle. And another octopus. And it goes in a cycle." To the question, "Is it a cycle?", she answered: "No. It's a pattern. Because it [three second pause] it repeats a sett." Danny offered the same response when asked what he had noticed about the way the animals had been arranged. He said; "That it's a cycle." With the follow-up question, "Is it a cycle?", he hesitated less than a second before changing "cycle" to "pattern."

Three of the ten correct and solicited responses to the question "What can you tell me about this arrangement of animals?" were more detailed than "pattern" (Reena) or "a pattern" (Anne, John, Ken, and Sara) or "in a pattern" (Cathy) or "a pattern?" (Michael). Debbie, for example, arrived to be interviewed before the animal models had been arranged in the linear pattern on the tabletop. She chatted about her cousin as this was being set up, offered the names of the animals with which she was familiar, at one point asked, "Do I have to find the matching pair or something?", and then began to help. The following is excerpt from her interview:

> Debbie: Another bee! Four bees. Four bees. Four bees. Four bees [three second pause]. Five bees [three second pause]. Six bees [three second pause]. (She is counting the total number of bees that have been placed, and are in the process of being placed on the table.)
>
> McMillan: It would have been better if I had this set up, but the roads were so-o icy, that I couldn't get here as fast as I hoped. That one between those two.
>
> Debbie: You could just put it here.
>
> McMillan: What do I need there? This? No.
>
> Debbie: Hum-em. I think a lizard.
>
> McMillan: I think I need a rhino [a rhinoceros beetle].
>
> Debbie: Why a rhino? Someone. Something came from there.
>
> McMillan: Ok. Now what do you notice about the way I've set up these animals?
>
> Debbie: Um-m. You're trying to do a pattern?

Willie and Marc each mentioned more than the pattern the other children reported seeing. Willie noticed that the twenty animal models had been arranged "in a line", and that they were "put in one in a group [the hippopotamus, an orange-yellow coloured beetle, and the rhinoceros beetle], or two in a group [the lizard and the octopus], or three in a group [the bumblebee]."

When asked if he noticed anything else, he answered: "There's different kinds of animals on this table. Cause. Cause they're. Cause they go. Cause they. Cause they go in the same pattern."

After naming the animals, "Mammal. Iguanas. An insect. Octopus. Beetle [with help]. Bees, or wasps", Marc took ten seconds to consider the question about their arrangement. He replied: "Animal, reptile, insect. There's one hippopotamus, two reptiles, and seven insects. One hip-, mammal, two reptiles, and seven insects." After being asked, "Now do you think an octopus is an insect?", Marc spent several minutes trying to figure out the classification of this animal. He referred to it as an insect, then a fish, and eventually asked: "What do you call that?" When told, cephalopod, he responded by saying: "Cephalopod. Then an insect, four insects, then a animal, two reptiles, two cephalopods, and then four insects." At this point Marc was asked, "So what is this?" He answered, "a pattern."

Seven of the children defined a pattern using the term "sett". A pattern was either a sett that "repeats"/"is repeated" (Reena, Annie, Michael) or "repeats itself" (Danny) or "repeats many times" (Cathy) or "repeats itself many times" (Sara) or "repeats itself many times over and over again"(Marc). The children who did not use "sett" in their definition, explained why they believed the model animals had been arranged in a pattern. Scott and John, for example, said: "Um. Because, um, it repeats itself", and "It keeps going [three second pause] to the end ...in the same order", respectively. Cindy's explanation was, "It's going recycling." Debbie, rather than explain what a pattern is, showed and described what a pattern isn't by removing the hippopotamus, setting it off by itself, and saying: "That [three second pause]. This is not going to be a pattern then because that doesn't have anything else." As she continued talking, she began moving an octopus and a lizard and the beetle in one of the two setts to different locations within the same sett, and said: "Um [three second pause] All this has to be the same. And pretend this one was here... The octopus right beside the rhino and the lizard right beside this beetle. That would, and then, this too right beside the bees. That wouldn't be a pattern. Because um, they have to be the same. In the same places. It wouldn't be a pattern."

Eleven of the fourteen children located the sett of ten model animals in the pattern. They did this by cupping their hands and placing their right hand between the first set of three bees and the second hippopotamus and their left hand at the beginning of the pattern next to the first hippopotamus. John and Anne identified the pattern as the sett, that is, all twenty model animals or both setts of ten were included. When John was asked, "Is this whole thing then a sett or is a sett something that's repeated", he answered, "repeated." He then located the sett by marking off the first ten animals in the pattern with his hands. Danny was asked to show where the sett for the model animal pattern would be immediately after saying that a pattern occurs "when there is a sett and it repeats itself." He pointed to each kind of animal and said: "This would be the bumblebee sett, and this would be the octopus. This would be the hippopotamus. The rhino beetle. This would be the hippo sett. Lizards." When asked how many times the sett repeated, he sat quietly for fourteen seconds before shrugging his shoulders. Ken, Cathy, and Michael said that the sett had been repeated "once" or "once more." John, Cindy, Reena, Sara and Marc said the sett was repeated "twice" or "two times."

All fourteen children repeated the sett when handed a bag containing one hippopotamus, two lizards, one orange-red beetle, two octopi, one rhinoceros beetle, and three bumblebees. John was the only child who was not successful on his first attempt. As he worked to duplicate the sett, he said the following: "Um. Hippopotamus. Lizard [nine second pause as he places the second lizard next to the first]. Beetle [continues working for twenty-five seconds]. Hippopotamus, lizard, beetle, octopus, beetle, bee, octopus, lizard, bee. In response to the question, "Now, have you repeated this sett? Is yours the same as this sett?", he paused to make a visual comparison. At the end of four seconds, he answered: "No. Ah-h. It's different." His second attempt was successful.

When it came to converting the three sett pattern into a cycle, two of the fourteen children, Danny and Anne, believed that they had done so, when they hadn't. Danny had been asked to repeat the sett and responded by saying, "Ok. I'll copy yours." At the end of twenty seconds, he had attached the ten model animals in the proper order to the established pattern. Before turning the animal pattern into a cycle, Danny said that a cycle is "when there's a sett and it doesn't ever stop." He then worked for twenty-three seconds moving the sett he had just completed to a position on the table directly under the two setts of the initial pattern. In response to the questions, "Is that a cycle?" and "What more do you need?", he said, "not yet" and "more [model animals]." At the end of forty-eight seconds, he had connected his sett with the beginning and ending of the pattern. The shape was a perfect semi-circle. In copying the sett, however, he had not considered that the order would have to be reversed. Rather than three bumblebees, one hippopotamus, two lizards, one beetle, two octopi, one rhinoceros beetle... (repeat the sett), he had three bees, three bees, rhinoceros beetle, two octopi, one beetle, two lizards, one hippopotamus, one hippopotamus, and so on.

Scott encountered the identical problem, but where Danny believed that he had created a cycle that would keep going forever and ever, Scott in making "a curve in it", exclaimed: "No! It won't work. I have to turn this around and put this here and put this here." In twelve seconds he had corrected his mistake.

Anne made the correct sett below the two sett pattern. With the request to turn the pattern into a cycle, she worked for twenty-seven seconds to shape the original pattern into an arc above and well separated from her copied sett. In response to the question, "Do you think that you've made a cycle", Anne nodded her head up and down. She said that a cycle "is a pattern that keeps on repeating."

Cindy and Sara, like Danny, initially said they needed more model animals to complete the cycle they had begun to construct. Annie responded, "I don't have enough" when she completed her sett and was asked what she would have to do to make the pattern a cycle. To the question, "Do you think you could put it [the pattern] into a cycle?", Marc responded; "Um-hum. If it's long enough." Cindy and Sara were told there were no other animals before they began to shorten the diameter of their circles. Annie was asked, "Well, what could you do with the ones that you have to make it into a circle?" It was a circle that she previously had said she would have to make. Her response was, "make it small." When Marc was asked, "What do you do if it's not long enough?", he answered, "I have to move this and this." The result was a cycle in the shape of an elongated and narrow ellipse. The cycles of John, Cindy, Scott, Cathy, and Michael were similar in form to Marc's. Willie, Debbie, Reena, and Ken produced cycles that were more like Annie's circle.

The following are eight children's descriptions of cycles or how to make the pattern into a cycle while retaining the positioning of the animal models within the three setts. The children speak of circles and making circles and a cycle that keeps on going or repeats over and over again and never stops. (Italicized passages represent the voice of the interviewer.)

> Well [two second pause]. Cause it. W-w-well. Cause. Cause the. Cause a pattern just goes in a line, but a cycle goes in a little circle that never stops. (Willie)
>
> Ah-h. It repeats over and over again and it never stops. *Ok. So what are you going to do have to do to put these [thirty model animals] in a cycle?* Um [eight second pause]. Make a circle? (John)
>
> Put them into a circle. *If they are in a circle why does that make it a cycle?* Ah-h [six second pause]. Cause cycles keep on going and going, and it never stops. (Debbie)
>
> Ah. I can just make this in a circle. *Is a circle always a cycle?* No-o-o. Like it can go around the room. *So if you were to explain to me what a cycle is, what words would you use?* Ah. Repeats itself over and over and never stops. (Scott)
>
> Um-m. A cycle never ends. You can't tell where the beginning is and where the ending is. And a pattern doesn't, does end. *So what's your plan?* To make it a circle. (Ken)
>
> You have to [two second pause] make it [two second pause] a circle... *And why is that a cycle and not a pattern?* Be-e-cau-au-ause, um, a sett [in a cycle] repeats over and over and over and over and over and it never stops. (Annie)
>
> A cycle is um when like um spring, autumn, fall, winter. It's like. It keeps ongoing. Like it's in a circle. It keeps on going. (Cathy)
>
> A cycle goes on. It never stops. Cause just like a [three second pause]. A cycle [two second pause]. Could I take one of those? [Michael makes a different cycle with four bees and four octopi]. That's a cycle. I've got bee-octopus; bee-octopus; bee-octopus; bee-octopus. *Right. And why is that a cycle?* Because it. It never stops... *So what are you going to have to do* [to make the three sett animal model pattern into a cycle]*?* Repeat the sett. Repeat the sett? Repeat the sett and make a circle. (Michael)

Six children whose descriptions are presented below did not mention a circle, but spoke of ongoing, forever repeating and never stopping cycles.

> It's [two second pause] It's a pattern that keeps on repeating. (Anne)
>
> When there is a sett and it doesn't ever stop. (Danny)
>
> It's going forever. *And what does that mean?* A recycle? (Cindy)
>
> A pattern repeats, and a cycle um is a pattern that keeps on going, and you can't see the beginning or the end. (Sara)
>
> Um-m. A cycle keeps on going forever and it will never stop and a pattern will stop at where it ends and from the beginning if you want to go backwards. (Reena)
>
> Cause they repeat theirselves over and over, and they never stop. (Marc)

As the children neared the end of the pattern to cycle component of the interview, six were asked if they could think of examples of cycles other than the one they had just made. Reena and Cathy mentioned the months of the year and the life cycles of an individual or what Cathy referred to as "people". The latter were described as "a child, teenager, adult, grandmother or grandpa" by Reena , and "they are babies, and then they are teenagers, and then they are adults, and then they die, then babies", by Cathy. Cathy also said that the months of the year are a cycle. Cindy, Scott and Ken talked about patterns that they could make with other animals and objects. These included Cindy's "fish-toad, fish-toad, fish-toad" cycle and Scott's square-circle-triangle cycle that is described in the following excerpt: "If you like ah-um, like painted a square and a circle and a triangle and kept it going around and ended with a triangle , ah-h in front of it. Right behind a circle and you keep it going." Scott also named each of the animal groups that had been discussed during science: mammals, insects, birds, fish, reptiles, and amphibians. When Willie was asked about other cycles, he answered,: "Um-m. Numbers. They're in a cycle. Cause. Cause. Cause they never stop [two second pause] going. If you go up to a hundred, then it goes up to two hundred, and then it will never stop."

DATA FROM QUESTION 3

3. I have [randomly] placed nine photographs of adult animals on the tabletop. Could you please put the photograph of each baby animal with its parent? While you are deciding which young animal goes with each adult, can you tell me what you are thinking? If the child is successful, ask: Why was this so easy for you? How did you know which baby to pair with each adult parent?

All fourteen children successfully paired the images of the young and adult bear, cat, cow, dog, elephant, horse, rabbit, sheep, and tiger. The images of the young animals were shuffled and in random order when handed to the child for sorting. All of the children worked from the top image to the bottom image in the set. While engaged in sorting, no images were passed over or placed aside by any of the children.

Danny, Anne, and John worked silently as they placed the images of the young animals on the image of the adult parent. Annie began sorting the images by saying, "Um-m-m. That you, it's just a smaller version of the bigger one", and then became quiet. When asked if she thought this was true of all mammals, and could she think of animals that are born not looking like a smaller version of the adult parent, she answered: "Um-hum. A frog. A salamander. Um-m-m [six second pause]. A_a-a-a [eight second pause]. Um-m-m-m [ten second pause]. At this point her conversation ceased until the pairs had been made.

The eleven children who talked as they established the young-adult pairings, generally gave the name of the adult animal and name of the corresponding young offspring. This was done in two distinct ways as the following excerpts from the interviews of Cathy and Debbie represent:

EXCERPT FROM CATHY'S INTERVIEW

McMillan: Well, here are the young, and what I want you to do is to take these cards and try to match the newborn animal with its adult parent. Ok?

Cathy: This will be easy.

McMillan: And talk about it while you're doing it.

Cathy: Ok. That's a foal, It goes with a horse. That's a lamb. It goes with the sheep. A bear cub. Goes with the bear. A calf. Ah, where's the cow? Goes with the cow. Puppies go with the dog. Babies rabbits go with a rabbit. Baby elephants go with the baby, the elephant. Tiger cub goes with tiger cub [places on adult tiger] and kitten goes with kittens [places on adult cat].

EXCERPT FROM DEBBIE'S INTERVIEW

McMillan: Now, I've got other pictures that show young animals. These are pictures of all the adults, and I want you to see if you can match up the picture of the newborn animal with its parent. Ok? I want to hear what you're thinking. So while you're doing it, just talk out loud and say every word that is going through your mind.

Debbie: Ah-h. This is a baby cow with the, where's the, with the mother right here. Here's the baby lamb with a sheep. Me, me, me. Me, me, me, me. I'm not going to have room enough. Here's the dog. Baby dog. Where's the big dog? No here's [three second pause]. This is the. Ah-h-h. This is the [two second pause] adult dog, and here's the dog. Jeesh, I'm getting mixed up here [three second pause]. Here's the mother tiger and here's the [three second pause] baby tiger. Here's the mother bear and the baby bear. Baby bear. Jeesh. These things don't cooperate with me. Um-m. Big bear. Little bear. That's a baby elephant. It looks cute [nine second pause]. It. Big elephant. Little elephant. Here's the [three second pause] little cat. Here's the mother cat. Here's the big horse and here's the-e-e l-l-little horsy. Um-m-m.

McMillan: What are these?

Debbie: Rabbits.

McMillan: Ok.

Debbie: Here's the mother rabbit and the bunnies.

Ken and Michael performed the pairing in a manner similar to Cathy. Willie's responses were like Debbie's, except that he stopped thinking aloud after placing the kitten on top of the cat, ("Oh-h. That's a cat. I'm [two second pause]. I'm putting the baby on top [three second pause]. Kitten. Got two of then. Hum. That's silly. Cat Foal. Foal...") the foal on top of the horse, the baby bear on top of the bear, and the lamb on top of the sheep.

Cindy, Reena, and Scott went beyond naming of the adult and its offspring, and commented on the similarities and differences observed in the old and young animal pairs. The majority of Cindy's comments were about "looking the same" and size. She used the adjectives "smaller" and "bigger" in reference to the foal and horse, the bunnies and rabbit, the calf and cow, the bear cub and bear, and the kittens and cat. When she held the image of the puppies in her hand, she spoke about a difference in colour. The images of the lamb and sheep and the differences portrayed in their "fur" elicited the following remark: "Ok. Lamb, goes with this. Anyways it kind of doesn't really look the same, because it doesn't have so much fur." Reena began with a focus on colour and size but slowly added features specific to the animals pictured. These included features like floppy or flattened ears and open or closed eyes. Her comments while pairing the calf and cow and the lamb and sheep follow.

> "Because the cow goes with the calf. And it goes. And it's the same colour. Um. Um [three second pause]. Um this one [the calf] just is a smaller version because it's a mammal."
>
> And the la-a-m-m-b is a, um, smaller version of its mommy except it's just a. It's mommy is, um, very fluffier, and this one's just a little fuzzy. And. Um, um, that one's called a sheep and this one's called a lamb cause it's a baby, um [two second pause] lamb, and that's a bigger, mommy sheep."

In his descriptions, Scott generally focused on similarities in physical characteristics evident in the images. Like both Cindy, who talked about elephants and tigers being jungle dwellers, and Reena, who said that baby rabbits "don't need to close their eyes when they are born", he also used information drawn from life experiences. When placing the images of the kitten and the cat together followed by the calf and the cow, he had these things to say:

> "These two go together. A kitten and a cat go together. Because, um, a kitten, um, it doesn't jump high, as high as the cat, and when it gets older, it jumps high like the cat. And it will turn into a cat. And um, it has hair like the cat, and the lids and the eyes and the nose are in the same places. And these things are the same. Oh, and a calf, um, goes with the cow. Because, um, um, Robert told me that, um, the calves get born by the, by the cows, because, um, because, um, it's just a different word and it starts out to be like it. And um, and um, and um. The ears are almost like the same except these they, they keep them all forward. And, the nose is just like the same and the same with the eyes."

Marc and Sara began pairing the images as soon as directions for sorting and thinking out loud were given. Marc finished after saying, "I'm attaching the baby to the adult." His response to the question, "Why was this so easy for you to do?", was: "Because they, um, like have the same body parts. And [two second pause] they, um. They. They're not as big. Or they not like be the same colour that [three second pause]. They still look, kinda look the same." Sara answered: "Because [two second pause] by these pictures [two second pause] you can just look at them and they look exactly the same... Not exactly. That's. This one is bigger and this one is smaller."

The responses to this question by nine of the children were similar to the answers given by Marc and Sara. In each case the child mentioned that the animals in the paired sets looked alike or resembled one another except in size. Michael, who named the animals as Cathy had, responded to the question, "Why was that so easy?", with the following: "Because [three second pause] they look the same, and I know. Ah-h. Because [two second pause] mam. The mammal's young, it looks like a smaller version of the adult." Anne, who spoke at the end of the sorting, answered: "Because most of, a-all these look the same. ...they just need a bit of growing."

Cindy, Danny, and Willie did not think that the babies of all mammals would look like the adult parent. Cindy pointed to the different colours of the puppies and adult dog and quantity of "fur" on the adult sheep and lamb. Danny said that when baby rabbits are born "their skin is red and their mom's is gray, or white." Unlike all other children, he also said: "Some [young and adult mammals] are the same size. The tiger is almost the same size as the mom." An excerpt from Willie's interview is given below:

> McMillan: Now, Willie, why was that so easy for you?
>
> Willie: Cause [two second pause]. Cause I. Cause I just looked at them closely, and I saw what they were, so I just, so I found the missing baby and put her on top.
>
> McMillan: Well, do you think that all baby mammals look like their adult parents?
>
> Willie: Some of them do.
>
> McMillan: Do you think that some of them don't?
>
> Willie: Yeah.
>
> McMillan: Which ones don't?
>
> Willie: Um-m. The ladybugs.
>
> McMillan: Are they mammals?

Willie: No. They're insects.

(At this point in the interview, a definition of mammal was given which caused a digression into a discussion of hair. Willie looked at the images of the cow and elephant and said, "Cows don't have hair." "But you know what? Elephants do not have hair.")

McMillan: Do you think that when a baby is born to a mammal that the baby is always like the adult in shape?

Willie: Um-m. No.

McMillan: Does it have the same number of legs and eyes and tail, nose, mouth, feet?

Willie: Yeah.

DATA FROM QUESTION 4

4. I have a model of a desert short horned lizard. You can hold it if you would like. Do you know what group of animals the lizard belongs to (mammal, reptile, amphibian, birds, fish, or insect)?
The lizard is a reptile. Do you remember the two reptiles we talked about during science? (snake and turtle/tortoise) Well, this lizard has a life cycle just like most turtle/tortoises and snakes. Even though we haven't studied the lizard, tell me what you think the lizard's life cycle could be.

Cindy, Reena, and Marc said that they had seen a lizard. Reena didn't know what the one she and her family observed in Hawaii was called, but she said, "...we got a good view of it." Scott and Debbie knew that the model was of a lizard before being told the name. When Debbie held it in her hand, she made the following comment: "I know, because I had three glow-in-the-dark lizards and three glow-in-the-dark snakes. I still got them. I just got them yesterday." She, along with Ken, Marc, Annie, Cathy, and Michael, identified it as "reptile" or "a reptile" when asked in what group or family of animals the lizard belongs. John said that it belongs to "[a] lizard's group", but selected "reptile" from a spoken list that began insect, mammal, amphibian, reptile. From a similar listing, Cindy responded, "no" to mammal, to bird, to fish, and to reptile, and "maybe" to amphibian. Scott equivocated between insect and reptile and eventually settled on "insects, I think." Scott and Willie, Danny, Anne, Reena, and Sara were told the lizard is a reptile.

Hearing the word reptile, Reena responded, "scales." When asked what different kinds of reptiles she had read and talked about in science, she answered: "Snakes and turtles." To a similar question, Michael responded: "Um-m-m. Crocodile. And reptile [thinking to himself]? Snake?" Asked about animals like the lizard with scaly skin, Scott replied: A crocodile. Ah-h and a snake. A turtle." The other eleven children were helped to reach this conclusion. They were reminded of the models of the snake and tortoise on display in the classroom or given fairly explicit hints like those reproduced here that were given to John: "One of them has scales on its body just like the lizard, but it doesn't have any legs. It slithers along. What might that be?" "The other one has scales but they're covered up by a shell, and it's really slow as it walks along. What might that be?"

Cathy talked about the life cycle of the turtle and the snake. She said that a baby turtle hatched from the turtle's eggs looking like "a smaller version of the adult." When asked what the life cycle of the lizard would be, she responded: "Um [three second pause]. Ah. Egg. Then adult. Oh no, not egg and adult. Egg, couldn't be a pupa [three second pause]." It wasn't until she was asked what would emerge from the egg and what would hatch from a lizard's egg, that she responded: "Ah! A baby turtle or a baby snake." "A baby lizard."

Two children, Willie and Marc, talked unaided and accurately about the life cycle of the turtle and/or snake, and what they believed the life cycle of the lizard would be. Debbie spoke only about the lizard. It's beginning "as a [three second pause] egg", and hatching as "a little baby" that "looks like its mother. Um-m-m [three second pause]. Mother is bigger."

Willie, unlike any of the other children, used a lizard from Question 2 to show what the lizard hatching would look like. This lizard was green, not the blue colour of the desert short horned lizard, and about one fourth its linear dimension. When questioned about these characteristics, Willie said that the hatchling would be that small, and that "it would be green, and when, but. If it was fully grown the, then it would look like this [points to the short horned lizard]."

Danny, Anne, and Reena did not immediately recall the life cycle of the turtle or snake. When it was suggested that they think of the three-dimensional models that had been on display their responses were not unlike those given by Willie, Debbie, and Marc. Excerpts of Danny's and Reena's interviews are presented below.

EXCERPT FROM DANNY'S INTERVIEW

> McMillan: Do you remember what the life cycle of the snake or the turtle is? How do the snake or the turtle begin?
>
> Danny: Um-m-m. They. They. Ah-h. The turtle starts out as a egg.
>
> McMillan. That's right.
>
> Danny: Then it. Then it goes in for some food. Then it grows.
>
> McMillan: Ok.
>
> Danny. Then it gets older. Then it turns into ah-h-h [two second pause] young adult.
>
> McMillan: A young what?
>
> Danny: A young kid.
>
> McMillan: The turtle does?
>
> Danny: It eats and [three second pause] turns. Ah-h. Youth.
>
> McMillan: Ok. So when the turtle hatches out of the egg does it look at all like the adult parent?
>
> Danny: It's just a smaller version.
>
> McMillan: Ok. So what do you think this [pointing to the desert short horned lizard] reptile would begin life as?
>
> Danny: It would get [three second pause]. It lays eggs.
>
> McMillan: Ok.
>
> Danny: And then the baby would be a smaller version.
>
> McMillan: Of the parent?
>
> Danny: [Nods head up and down.]

EXCERPT FROM REENA'S INTERVIEW

> McMillan: Do you remember the life cycle of the snake and the turtle? How do they begin?
>
> Reena: Egg.
>
> McMillan: Um-hum. What hatches out of the egg let's say of the turtle?
>
> Reena: Ah-h-h. A smaller version of its mother.
>
> McMillan: Since this is a reptile, what do you think its life cycle would be?
>
> Reena: Egg. Smaller version of its mother.
>
> McMillan: And then what? What does it become after it hatches?
>
> Reena: Adult.
>
> McMillan: But what does it have to do in order to become an adult?
>
> Reena: Um-m. Eat and grow, eat and grow.
>
> McMillan: Ok..

John, Cindy, Scott, Ken, Annie, and Michael needed help recalling the life cycles of the snake and turtle. John and Michael weren't certain how the cycle began. Cindy, Scott, Ken, and Annie knew that it began as an egg, but when asked what hatches from the egg, answered: "Um-m, larva?"; "Ah-h-h. Ah-h-h. I forgot."; "Um-m. A nymph. Oh, no! Um. I forgot."; and "A larva?", respectively. In most cases a question like the one in the excerpt below and asked of Scott was sufficient to trigger the appropriate response. This was:

> McMillan: Well, do you remember the models we had [in the classroom]? There was a large snake and a snake's egg. What was coming out of the snake's egg?
>
> Scott: A little snake!
>
> McMillan: How is it different form the adult snake?
>
> Scott: Um-m. It's not as long as it is. And um-m. it's. And the, the green spots are in like, like in the brown or whatever holds the spots. He doesn't really have as much as the mum.

McMillan: Ok. So they are different in size and in the colour that they have?

Scott: Um-hum.

McMillan: Ok. What do you think this [the dessert short horned lizard] reptile's life cycle would be?

Scott: Ah-h. Egg. Little, um, um, lizard. Ah, and then adult lizard.

McMillan: Ok. So it eats and grows and then becomes the adult.

Questions like the one asked of Scott did not help Cindy. She recalled that a turtle emerged from the turtle's egg and that "it does look the same [as the adult]" only smaller. Her response to the question about the lizard's egg, however, resulted in an answer heard before in the context of the turtle: "Um. Um-m-m [four second pause]. Hum. A larva? Ah-h-um. Hum [three second pause]. I can't even remember." Sara said that the life cycle of the lizard would be the following: "Egg. Larva. It sheds its exoskeleton. Pupa." Annie, who is mentioned above as saying a larva would hatch from the lizard's egg, was helped to realize that it would be a baby lizard when she was reminded of the snake and tortoise models. When asked, "What makes you think that?", that it would hatch as a smaller version of the adult, she answered: "Um-m, because it doesn't go through metamorphosis."

DATA FROM QUESTION 5

5. I have models of three animals that look a lot like lizards, and many people seeing them for the first time believe that this is what they are. They are not lizards, though. Lizards have scales. The skin of this animal is smooth. Do you know what these animals are called? (salamanders) Do you know the animal group they belong in? (All salamanders are amphibians.) Do you remember other animals that we talked about that were also called amphibians? (frog and toad). Even though we haven't studied the salamander in detail, tell me what you think the salamander's life cycle could be.

Eight children, Willie, Reena, Ken, Sara, Annie, Marc, Cathy, and Michael, identified the model animals as salamanders. Debbie and Cindy said they were lizards. Anne, John and Danny couldn't remember what they were called. Scott was inadvertently told.

Nine of the children said that salamanders are amphibians. Of these nine, Marc and Scott were asked how they could tell that the model salamanders were amphibians and not reptiles; what was the difference between the two groups (classes). Marc replied: "Salamanders look. They have skinnier bodies. Ah-h. They're longer than a. They're amphibians. They don't look like um their mother when they're born." Scott answered: "Um-m. Because um this [the model salamander] can go in the water and land, and this [points to a model of the desert short horned lizard] can't. This can't go in the water." Ken and Sara responded, "reptiles" to the question, "Do you have any idea what animal group salamanders belong to?" Cindy answered a similar question as follows: "They don't shed. So they can't be insects." Debbie and Anne, were inadvertently told "salamanders are amphibians" when given the common name.

"A frog" or "frogs" were the answers given by twelve of the children when they were asked to name amphibians other than the salamander. Willie, Reena, and Sara also mentioned the toad. Debbie said "fish." After naming salamanders and frogs, Scott said: "Ah-h-h [three second pause]. Birds. No-o-o. I mean ducks." When asked, "Ducks? Are they amphibians?", he responded, "yeah."

All of the children talked about the life history of the frog, from egg to adult. As illustrated in the four excerpts below, the descriptions varied in definitiveness and, thus, numbers of intervening questions.

EXCERPT FROM SCOTT'S INTERVIEW

McMillan: Now, what was the life cycle of the frog?

Scott: Um. Um. A egg.

McMillan: Um-hum.

Scott: Ah. A tadpole. And then it forms its back legs. And its front legs. And. And. And its. And. And its mouth. And um. His um. And then he's. He has a little tail. And um he eats his tail. It should be. Ah. To have a big mouth and tongue. And um. It's a, a young little frog. Then it's a full grown adult.

EXCERPT FROM CATHY'S INTERVIEW

McMillan: Now, what was the life cycle of the frog and the toad? Do you remember when we read and talked about that?

Cathy: An egg.

McMillan: Right.

Cathy: Tadpole.

McMillan: Um-hum.

Cathy: And. Ah-h. Young frog or toad and then a frog or toad.

McMillan: Ok. So what happens to the tadpole between the time it comes out of the egg and then is a young frog?

Cathy: Well, first it gets its back legs.

McMillan: Ok.

Cathy: Then its front legs. And then his, um, tail disappears, and he comes out of water, and then he just gets bigger after that.

EXCERPT FROM ANNE'S INTERVIEW

McMillan: Do you remember the life cycle of the frog?

Anne: [Four second pause]. Un-huh.

McMillan: Ok. How did it begin?

Anne: Egg.

McMillan: Right.

Anne: And then it had, it had a little, a long tail. And then it had its back legs.

McMillan: Ok. And then what happened to it?

Anne: It, he got his front legs and his tail started to shrink.

McMillan: And then what did it look like?

Anne: It looked like his, the mom. But it still needed more growin'. Just a little bit more.

McMillan: Was it the same size at the mom?

Anne: No.

McMillan: Was it bigger?

Anne: No.

McMillan: What was it?

Anne: It was smaller.

McMillan: Ok. Do you remember what they call the little animal that comes out of the frog's egg?

Anne: Tadpole.

McMillan: Ok.

EXCERPT FROM MARC'S INTERVIEW

McMillan: Now, what was the life cycle of the frog or the toad?

Marc: Um-m. Egg. Tadpole. Adult.

McMillan: Ok. Does it just go from a tadpole [interrupted]

Marc: Egg, tadpole. Egg, tadpole, young frog, and then the adult?

McMillan: Ok. What happens between the time when the tadpole hatches out of the egg and it becomes a young adult?

Marc: It [breathes in] looks like it just needs to grow to be the adult.

McMillan: So the tadpole looks like a miniature frog?

Marc: No.

McMillan: What does it look like?

Marc: Ah-h. It looks like a small fish. A little fish.

McMillan: What does it get that makes it more frog-like?

Marc: Its back legs.

McMillan: And then what happens?

Marc: Its front legs come, and it develops the lungs, and ah-h, then it. It makes, ah-h, its making its tongue so it eats its tail, and then, ah-h-h, it's the-e, almost the adult, and then the adult.

Debbie was the only child to report a life cycle different from egg, tadpole, young adult, mature adult. She answered the question with: "Egg, larva, pupa, adult." When asked, "Is that what the frog does?", she responded: Ah-h. The frog is, um, egg, larva [two second pause], ah-h-h." With the subsequent question, "What was the thing that hatched out of the frog egg? Try to remember the models of it that were on the table.", she said: "Oh yeah! Um. Um. Egg [three second pause]. Tadpole [three second pause]. Youth."

John said that the tadpole emerging from the egg "has no legs". It has "a little tail at the end of its body." When asked, "What's the first change that happens to its body?", he answered: "Ah. It gets the front legs" and then, "the back legs."

Seven children say that the developing tadpole "eats his/its tail" (Danny, John, Cindy, Scott, Reena, and Marc) or the "stuff inside the tail" (Michael) to make a tongue. Annie explained it thus: "It develops its back legs, and it eats its tail, not like that, but it grows into its body and then becomes a tongue." When Marc was asked where he had heard that the frog eats its tail, he responded: "Um. When we were studying science. The frog eats its tail [clears throat] because it can't eat because it's making a [two second pause] long tongue to catch flies. I heard it when we were studying science." Willie, Anne, Sara and Cathy do not mention the eating of the tail but say that "the tail shrinks", the "tail started to shrink", the tadpole starts "to sunk in its tail", and "the tail disappears", respectively.

Responses to the question, "The salamander is an amphibian, what do you think its life cycle could be?", are presented in the following table. (Italicized passages represent the voice of the interviewer.)

Name	Life Cycle of the Salamander
Willie	"Um-m. Egg. Nymph [picks up the spotted salamander model, holds it in both hands, and scrutinizes it while talking]. Kind of a tadpole like thing. But I. Except it already has two back legs and two front legs. It. It. It. It. It. It gets. It. It. It gets a little bit of spots on it and it grows and it eats and grows. And as soon as it. It. It. It. And it almost got lots of dots, but, except it doesn't have its right tail for going on land yet. And then it gots part of its tail. And then more of its tail. And then more of its tail. Then more of its tail with lots of spots. Then more of its tail with not, no spots, and then more of its tail with no spots Then. It. It. It. It's all the way to the end tail and then it's fully grown. Then it's a fully grown salamander."
Danny	"As a egg. A young. A smaller version of the mom."
Debbie	"Egg. Tadpole. Then it starts to get gills. Youth."
Anne	"The same thing [as the frog]? A long tail. Oh! A egg. A tadpole. And then it has back legs. And then it loses his tail [two second pause] with his arm." *Does it look like it would lose its tail like the frog?* "No. It grows his tail."
John	"Ah-h-h [eight second pause]. Ah-h." *Do you think its an egg? Like the frog and toad"* Ah-h. Yeah. *And what do you think comes out of the egg?* The amphibian looks just like a tadpole. *Do you suppose it gets legs just like the frog does.* Yep. *What happens to the tail?* They eat. It grows."
Cindy	"Em em em [intonation exactly as if saying I don't know]. I don't know."
Scott	"Egg. Um. Tadpole. Ah-h. It forms it's back, no it has it always, its back legs and front legs. And adult."
Reena	"The same as the frog? Egg. Tadpole. Back legs. Front legs. Um. Eats its tail. *Now, do you think this one loses its tail?* No-o-o. It grows its tail. Ah-h-h. Salamander, young salamander.
Ken	"Egg. Um-m. Tadpole. Small salamander. And [two second pause]. ...the salamander comes out of its egg, ah-h, of its egg, it has four legs already. *Do you think it loses its tail like the frog?* Nope."
Sara	"Um-m-m. The same [as the frog's life cycle]. A egg. A tadpole."
Annie	"Just like that [the life cycle of the frog]?" *How would that be? Do you think they lay eggs?"* Um-hum. *And then what hatches out of the eggs?* A-a-a. Something like a tadpole [two second pause] except it has its front and back legs. *And then do you think it just grows and becomes the adult?* Um-m. No. It has to eat and grow."
Marc	"Egg. Um-m. A young salamander and a. But. And then an adult salamander, but it doesn't look like the adult salamander. Um-m [three second pause]. It doesn't have its front legs. Um. Um. It's not as long. Ah-h-h. *So does the tadpole of the salamander look just like the tadpole of the frog?* No. It has its legs."
Cathy	Um-m. Egg. Um-m. Couldn't be a [six second pause]. Couldn't be a tadpole. It isn't called a tadpole. It's called. Oh. I forget what it's called. It's called. It's called. It's like it has it's legs and [two second pause] it has a tail and it swims. Da. Da. They, da, lose their tail. No they don't lose their tail. Um. I don't know. They. Ok. They lay the egg. Um. A little tadpole thing. Then they, ah, little salamander thing."
Michael	"Um-m-m. Starts out as an egg in the water. Then it hatches out. And [three second pause] s-s-swims around? Um-m-m. What does it look like [whispers to self]? It looks-s-s like the frog. Ah-h-um-m [eleven second pause] tadpole? Um-m-m. It changes less. Because it [two second pause]. It doesn't [two second pause] eat the tail. The tail doesn't go away."

DATA FROM QUESTION 6

6. Six weeks ago we read and talked about grasshoppers and crickets. I have a diagram that a friend of mine drew. He was just learning about these insects, and he wanted to do a drawing of the grasshopper's life cycle. Take a look at his diagram. Tell me what you see. What stages has he shown? Point to the pupa and ask, what do you think this might be? If you were his teacher, what would you say to him about the life cycle he has drawn for the grasshopper? If the child sees an error in the diagram, a pupa that shouldn't be in a life cycle without a larval stage, show the corrected diagram and ask if s/he believes it is a more accurate (better) representation of the life cycle of the grasshopper. What is it that makes her/him think it's' "better" than my friend's attempt.

Name	Egg	Nymph	Adult	Pupa
Willie	"An egg."	"Ah-h. A young grasshopper."	"An adult."	"A pupa."
Danny	"A egg."	"A cricket."	"An adult"	"He's turning into adult."
Debbie	"The egg."	"Cricket. Ah-h. A larva."	"A adult."	"A nymph."
Anne	"Egg."	"Cricket."	"Cricket. Adult."	"His old skin."
John	"Egg."	"Larva. No! Larva."	"Adult."	"Because he was shedding his skin"
Cindy	"Egg."	"Um. Larva."	"Adult!"	"Pupa."
Scott	"Egg."	"A nymph."	"Adult."	"A pupa."
Reena	"An egg."	"A nymph."	"An adult."	"Pupa."
Ken	"Egg."	"Um-m. Larva."	Adult inferred.	"Pupa."
Sara	"Egg."	"Larva."	"Adult."	"Pupa."
Annie	"An egg."	"Um-m. A grasshopper. Except not a full grown grasshopper."	"A full grown grasshopper."	"Um-m-m-m. [three second pause]A grasshopper shedding its exoskeleton."
Marc	"An egg."	"A nymph."	"An adult."	"[Six second pause] A larva. Ah-h. Ah-h-h. Um-m-m."
Cathy	"The egg."	"A young caterpillar. Not a caterpillar! A cricket."	"Ah. A grass-hopper. Adult."	Um. Chrysalis or something.
Michael	"An egg."	"A larva. A-a-a nymph!	"An adult."	"Um-m-m. Hum. What's coming out of the egg? I don't know. He put a pupa."

All of the children identified the egg and adult stages in the lifecycle of the cricket/grasshopper. The drawing of the grasshopper nymph was variously called a "cricket" (Danny and Anne), a "young"/"not fully grown grasshopper" (Willie, Annie, and Cathy), a "larva" (Debbie, John, Cindy, Ken, and Sara), and a "nymph" (Sott, Reena, and Marc). Michael initially identified the illustration as "a larva" but instantly changed this to "nymph".

The illustration of the butterfly chrysalis was identified as a "pupa" by seven of the children (Willie, Cindy, Scott, Reena, Ken, Sara, and Michael). As the following excerpts suggest, the understanding from which the term, "pupa", was uttered, varied.

EXCERPT FROM SARA'S INTERVIEW:

> McMillan: I have a friend who has been studying grasshoppers, and he did these drawings because he wanted to show the stages
>
> Sara: Egg [points to the egg]. Larva [pointing to the nymph]. Pupa [pointing to the chrysalis]. Adult [pointing to the adult].
>
> McMillan: You think this [pointing to the nymph] is the adult grasshopper?
>
> Sara: No. Larva. This one's the larva. Pupa [pointing to the chrysalis]. Adult [pointing to the adult].
>
> McMillan: Do you think he was right, then, when he showed the grasshopper looking like this. That the grasshopper does have a pupa state?
>
> Sara: Uh-hum.

EXCERPT FROM KEN'S INTERVIEW:

> McMillan: What do you think he was drawing here?
>
> Ken: Egg.
>
> McMillan: And what do you think this [pointing to the nymph] would be?
>
> Ken: Um-m.. Larva.
>
> McMillan: Ok. And what do you think happens to that larva? What do the larva usually do?
>
> Ken: It eats and grows and molts.
>
> McMillan: What does it mean to molt?
>
> Ken: Ah-h. Sheds it, its old exoskeleton.
>
> McMillan: Does that usually happen a lot of times to an insect?

Ken: Ah-h. Yeah.

McMillan: Because that's how they get bigger, isn't it?

Ken: Um-hum.

McMillan: Ok. Now what do you think this is [pointing to the chrysalis] that he drew?

Ken: Pupa.

McMillan: Now do you think a grasshopper has a pupa?

Ken: Um-m-m [8 second pause].

McMillan: Does it have three stages in its life cycle or does it have four?

Ken: Four.

McMillan: Four? Because here's another drawing that someone did. They also have an egg. And they've got a little one that grows and molts, grows and molts, grows and molts. Each time getting a new exoskeleton. Until the final molt when it has its adult wings and probably sexual organs so it can mate. Now which one of these do you think is the most accurate?

Ken: Um-m-m [6 second pause]. Hum.

McMillan: It would depend on whether or not you think a nymph comes out of the cricket or grasshopper egg. Or is it a larva that's going to have a pupa state, where it rests.

Ken: [Seven second pause] Nymph.

McMillan: So what would you tell him that was wrong with his drawing?

Ken: Because it went egg, larva, pupa.

McMillan: So what did he do wrong?

Ken: He um didn't put the nymph in.

McMillan: Ok. Should he have had this? The pupa casing?

Ken: Um-m. Um-m. No.

EXCERPT FROM REENA'S INTERVIEW

McMillan: So what would the stages be in its life cycle?

Reena: Egg, nymph, adult.

McMillan: Ok. And what is the nymph? What does the nymph look like for a cricket?

Reena: Ah-h... I don't know.

McMillan: When it hatches out of the egg, what do you think it looks like?

Reena: Ah-h-h.

McMillan: I've got a drawing that might help. A friend of mine has been studying crickets and grasshoppers, and he did this drawing. Now, what do you think that [pointing to the egg] would be?

Reena: He drawed that!?

McMillan: Um-hum. What is this?

Reena: Oh [exhales]. An egg.

McMillan: And what do you think that would be [pointing to the nymph]?

Reena: A nymph [whispered].

McMillan: Yes. And so what's this [pointing to the adult]?

Reena: An adult.

McMillan: Right. And in order for the nymph, because it's an insect, to get to the adult, what is this little nymph going to have to do?

Reena: Um. Eat and grow. Eat and grow.

McMillan: What does it have on the outside of its body?

Reena: Oh! Exoskeleton. It molts!

McMillan: Ok. And then what happens when he molts?

Reena: He gets a different coloured skin and becomes an adult.

McMillan: But does it just take one molt to do that? Does he just change his exoskeleton once?

Reena: A lot of times. Several times.

McMillan: What do you think my friend drew here [pointing to the chrysalis]?

Reena: Pupa.

McMillan: If this is the nymph [pause] egg, nymph, adult, should it have the pupa?

Reena: Oh. Let's see! Young, um, grasshopper.

McMillan: Young grasshopper? Isn't this [pointing to the nymph] what you called the young grasshopper?

Reena: [Giggles.]

McMillan: Do you think that this belongs in this life cycle drawing?

Reena: No-o-o.

McMillan: So would this one [show the diagram of accurate life cycle] be more [interrupted]

Reena: A caterpillar.

McMillan: accurate?

Reena: Yeah.

EXCERPT FROM SCOTT'S INTERVIEW:

McMillan: Do you remember what the life cycle of the grasshopper was?

Scott: Um-hum. Um. Egg.

McMillan: Um-hum.

Scott: Ah-h-h. Larva? No, never a larva. Nymph! Adult.

McMillan: Ok. And what is a nymph?

Scott: Ah-h. A young. It's a. When it eats and grows and its young. And it's not fully grown. Or it's not just a really grown one.

McMillan: Ok. So when it eats and grows how does it become larger?

Scott: Ah. Because it um. When it. It because it gets bigger when it has eaten.

McMillan: Is there something special about insects?

Scott: Um-m. Yeah.

McMillan: What?

Scott: They molt.

McMillan: Right. And why do they have to molt?

Scott: Because their exoskeleton gets um too tight on them.

McMillan: Ok. Well I have a friend that did this drawing of what he thought the life cycle of the grasshopper would be. I want you to look at it and tell me what you think that is [pointing to the grasshopper egg]?

Scott: Egg.

McMillan: What's this [pointing to the grasshopper nymph]?

Scott: A nymph.

McMillan: What's that [pointing to the adult grasshopper]?

Scott: Adult.

McMillan: Ok. Now what do you think this is [pointing to the chrysalis] that he included in his life cycle?

Scott: A pupa.

McMillan: Does that belong in the life cycle of a grasshopper?

Scott: Um-m. No.

McMillan: Why?

Scott: Because um. It's. Because this isn't a larva.

McMillan: Does a nymph ever have to rest the way a larva does?

Scott: No.

Like Cathy who called it a "chrysalis or something", Cindy said: "It, it almost looks like a, looks like a, um, um, caterpillar." This was the interpretation made by Reena [see excerpt above] and the interpretation made by Marc as shown in the excerpt below:

Marc: [Points to grasshopper egg] An egg. [Points to grasshopper nymph] A nymph. [Points to adult grasshopper] An adult.

McMillan: What's that [pointing to the chrysalis]?

Marc: [Six second pause]. A larva. Ah-h. Ah-h-h. Um-m-m.

McMillan: Does it remind you of something?

Marc: Bu. A-a lady. Ah-h-h caterpillar.

McMillan: Does it look like its cocoon?

Marc: It doesn't have a. The cricket doesn't have a cocoon.

McMillan: So is this drawing very good. I mean it may be drawn nicely, but is it accurate in terms of that life cycle?

Marc: [Shakes head from side to side.]

McMillan: What should he have done instead?

Marc: Egg, nymph, and then just an adult.

Danny said that the drawing of the chrysalis was the young cricket turning into the adult. To the follow-up questions, "And what would you call this [chrysalis]? Is there a name for this? Is it a case? Or a cocoon? Or do you think it's the exoskeleton?", he answered: "Yeah. Exoskeleton. It eats and grows [two second pause] and then it, sheds its skin." The exoskeleton or old skin or grasshopper in the process of shedding its exoskeleton were how the drawing was interpreted by Anne, John and Annie.

Debbie, who identified the drawing of the nymph as a cricket/ larva, said the drawing of the chrysalis was a nymph. She said that a larva emerges from the egg, becomes a nymph, and that the nymph becomes an adult.

DATA FROM QUESTION 7

7. I have drawings that show the life cycle of a mealworm beetle. I would like you to arrange them in the order that you believe they would occur during the life of a mealworm beetle, and to tell me what you think happens during each stage.

Anne took eighteen seconds to arrange the four drawings in the sequence egg, larva, pupa, adult. She forgot what the second image in her sequence was called. When asked if she thought it would be a larva or a nymph, she answered, "nymph" and said that the nymph "eats and grows" and becomes a "larva". The larva would molt before becoming the adult beetle.

Cindy began by discussing the life cycle of the ladybug/lady beetle. She said a larva would hatch out of the ladybug's egg, and that it would spend most of its time "eating and growing and shedding. ...and then the last time it sheds, it's an adult." When she was given the drawings of the mealworm beetle to order, the sequence became egg, larva, pupa, adult. She said that the pupa was when "it gets its shell for the wings and gets, um [two second pause] its legs, furrier, you know?" She also mentioned antennae and said that during the pupa state, "it's getting all the way to the adult, you know. Adult."

Sara laid the drawings on the table in the sequence egg, larva, pupa, adult beetle. When asked: "Do you think this is the larva?", she replaced the drawing of the larva with the drawing of the pupa saying "this one [the drawn pupa] is bigger than this one [the drawn larva] and this one should be bigger than this one. Her action and comment led to the following exchange:

> McMillan: But look at this [the drawing of the larva]. What do you see when you look at the head?
>
> Sara: Two horns.
>
> McMillan: Those are jaws. Their mouth parts actually come out, project. So remember, what does a larva mostly do in an insect's life cycle?
>
> Sara: Um-m. It-t-t eats and grows.
>
> McMillan: Yes. It eats and grows, and it gets too big for its exoskeleton. What is this then [the drawing of the larva]? Do you still think that's [the drawing of the pupa] the larva?
>
> Sara: No. I think that's the pupa now.
>
> McMillan: Why?
>
> Sara: Because [three second pause]. Um-m-m. We just talked about it, and I thought about it, and this one [the drawing of the pupa] doesn't eat anything, and this one [the drawing of the larva] should go here [after the drawing of the eggs].
>
> McMillan: And what will this one [the drawing of the pupa] do?
>
> Sara: Um-m. Spin. A-h-h-h [three second pause] case.
>
> McMillan: And what does it do in that case?
>
> Sara: It changes.
>
> McMillan: Changes?
>
> Sara: Into an adult.

Each of the eleven children not yet mentioned, arranged the drawings in the egg, larva, pupa, adult sequence of the mealworm's life cycle and used the correct terminology in naming the four stages. Willie, Danny, Debbie, John, Scott, Reena, Ken, Marc, Cathy, and Michael said that the larva was the stage in the life cycle in which the eating, growing, and molting/shedding of the exoskeleton occurs. During the pupa stage, they said that the mealworm makes a case and rests and changes into the adult beetle. Annie said that the larva "eats and grows" and that the pupa "sheds its exoskeleton" and then spends the time "resting and growing and changing" into the adult. Cathy and Reena, like Annie, said the pupa grows. When Marc was asked if the mealworm pupa would eat, he answered, "No."

To the question, "How did you know that [was the larva]?", Scott replied: Because um. Because um, it doesn't look like this [pointing to the drawing of the adult beetle]. And when we did the drawing [of the ladybug's life cycle], um [two second pause] um, it almost looked like this..." Marc selected the drawing of the larva as the mealworm's larval stage saying: "This doesn't look like it would when it grows up, and it has a long tail, and it kinda looks like the ladybug larva." Reena said she knew, "cause it had a longer tail, and this one [the drawing of the pupa] had a shorter tail." John said: "Because it's long." When Danny was asked how he knew the drawing of the pupa followed the mealworm larva in the sequence, he responded: "Because its legs are tucked in underneath." Willie's explanation for his sequence is given in the excerpt below.

> McMillan: Ok. What comes out of the egg? So we'll put that [the drawing of the eggs]first.
>
> Willie: Th-e. And then I think this [the drawing of the mealworm larva].
>
> McMillan: And what is that?
>
> Willie: It's. It's a little thing with a tail.
>
> McMillan: And what do we call it when it comes out of the egg?
>
> Willie: Ah-h.. A larva.

McMillan: Um-hum. Why did you think that was the larva and not one of these [drawings of the mealworm pupa and beetle]?

Willie: Cause. Cause this. Cause this is a beetle thing, and, and, and I thought it was. I thought it was the second life cycle. I thought it was a larva.

McMillan: Ok. And what made you think that? What on its body gave you that idea?

Willie: Because it had a tail, and I thought it, I thought it would swim, keep in the water until it, and then it had its pupa in the water.

Willie: Ok. So which one of these is the pupa?

Willie: This one [the drawing of the mealworm pupa].

McMillan: How did you know that Willie?

Willie: Because it looks like, it looks like the beetle's pupa. Like that. Cause I knew it. Cause I knew that this [the drawing of the mealworm beetle] was an adult.

McMillan: And how did you know that was the adult?

S - Cause it. Cause it had the wings and had the, the, the six legs, and it had the wings, the wing case, and, and it had the head, and it didn't have that little tail thing anymore.

DATA FROM QUESTION 8

8. Here are a few beetles that I have borrowed from the Entomology Department (pinned specimens). Look at the pairs of beetles that have been pinned side-by-side. They are the same kind of beetle. What do you notice about them? Do they look the same? In what way are they alike? How are they different? If a child mentions size (bigger and smaller) ask, why do you think they are different sizes when they are the same kind of beetle? Do you think they are the same age? Which one is older?

Within seconds of placing the two boxes of pinned beetles on the tabletop, all of the children spoke about the differences in size of the paired beetles. These comments are presented below for all fourteen children along with each child's explanation(s) for one beetle being bigger or smaller than the other. With the exception of Reena, who said she didn't know why one would be larger, and Marc, who spontaneously attributed size to gender, age is the reason given. Larger, bigger beetles are "older" (Willie, Ken, and Annie), "adults" (Anne and Scott) or "full grown" (Sara). The smaller, tiny, little beetle is "younger" (Cathy and Michael), "a smaller version of the adult" (Danny), a "baby" (Anne, John, Cindy, Scott, Sara, and Debbie), a "larva" (Michael) or a "pupa" (Debbie).

NOTE: Italicized passages represent the voice of the interviewer.

Willie: "...this one's small and this one's bigger and this one has small horns and that one has bigger horns. *Why are these different sizes?* Cause [two second pause]. They're. Cause they're bigger. [Why are they bigger?] Cause they [two second pause]. Cause they. Cause they. Cause they're older."

Danny: "This one is smaller than this one. And this one is smaller than that one. They're just a smaller version of the adult. *So where's the adult?* Here and here [pointing to the largest of each pair]. Here and here [pointing to the largest of each pair]. *So you think the bigger one is always the adult?* Not always. *When is it not?* When it gets older and older and older. *What happens to it?* It dies."

Debbie: "Holy! That one's small! This one right here looks like a baby sort of. Just hatching out [three second pause] of the egg. *What about these two beautiful green ones?* Holy! Um [three second pause]. I know that one's not a [two second pause]. Not a, like a, ah-h, adult because it's more [three second pause] like littleish. I used. It looks like, um, [three second pause]. Um-m-m. It looks like ah-h [three second pause] pupa. Sort of pupa."

Anne: "This one's tiny and this one's bigger. *Why do you think this one is so much bigger if they're supposed to be the same kind of beetle?* Because that's the baby [pointing to the smaller beetle.] That's the adult [pointing to the larger beetle]and that's the baby [pointing to the smaller beetle]."

John : "*Ok. Now what do you notice about these two?* They look the same, but that one's smaller. That's bigger. *Now why do you think one is smaller?* Because that's the baby, and that's the [two second pause] adult. *Do you think that's true here. The small one is the baby, next to the adult?* Yeah. That's the adult [pointing to the larger of the pair of beetles]."

Cindy: "That one's smaller. That one's small, and that one's big. *That's tight. Now do you think these are both adults?* N-n-n-n-n. Well, that one could be [pointing to the larger of the pair]. *What about this one?* I think that's, a little one. A baby one. *What does a baby insect look like though?* [Cindy looks into the box, her nose almost touching the plastic cover.] It's hard to see them."

Scott: "*They're put in pairs and each pair* [interrupted] Oh! I know. This is the adult here [pointing to the larger beetle] and this is the baby [pointing to the smaller beetle]. *Do you think the same of these?* Um-hum. This is the adult right here and this is the baby. And I know that this one is too. This is the adult. Because it, um, it looks very bigger than this little thing way down here, this little baby."

Reena: "Ah-h-h. That one's smaller and other one's bigger. One had big jaws. The other one's huge. *Do you have any ideas why one might be larger than the other?* Um-m [five second pause]. [Do you have any ideas why that might be?] No. *Do you think these are adults?* [Five second pause] Yeah!"

Ken: "Ah-h. That one's bigger, and that one's smaller. *Why do you think that would be?* Ah-h [five second pause]. Um. One's older.

Sara: "This one's bigger, and this one's smaller. Way smaller. *And why do you think one would be bigger than the other?* Because this one is the baby [pointing to the smaller beetle]. *Ok. And these two they're almost the same size, aren't they?* Yeah except. Yeah. This one has horns sticking out and that one doesn't. *Do you know why that would be?* Because this is full grown [pointing to the larger beetle] and this one isn't."

Annie: "Um-m-m-m [three second pause]. This one's smaller. This one's darker. This one's lighter. *Ok. Do you think that one is older or younger than the other?* Um-hum. *Which do you think is oldest?* That one. *And why do you think that?* Be-ecause it's bigger. *What about these two, the beautiful green ones?* Um-m. This one's older. *How do you know?* Because [two second pause] it's fatter and longer."

Marc: " They look the same only smaller. *They're both smaller?* Ah-h. No. They're. This one's bigger. That one um-m. They have almost the same body parts, except that one has the horns. *Now why do you think they would be so different if they're both the same kind of beetle?* That one's the male or female, and that one's the male or female, and the female or male is bigger than the other. *So do you think that even though there's such a big size difference that they could be the same age?* Yeah. Or that one could be the adult and the one could be the [two second pause] um-m-m littler one. *Now think about it Marc. What is the littler one?* The larva. *Does it look like a larva?* No. It. That one's um-m a male or a female, and that one's a male of a female."

Cathy: "This one is smaller and this one is bigger. *Why do you think that's the case?* Ah. Um. Um. It's a smaller beetle or bug. *But when I say they're the same kind, it would be as if we had two ladybugs, both from the same parents.* Oh. Ok. Um. Um. Maybe that one's littler and that one's bigger. *Now what do you mean that one's littler and that one's bigger, because you've already said that that one is smaller and that one is bigger?* Yeah. *Do you think they're both the same age?* Ah [two second pause]. Um. Not really. *Ok. What do you think is the difference in terms of age?* Ah. Because. Um his legs are bigger [pointing to the larger beetle]. His legs are really small [pointing to the smaller beetle]. His jaws are bigger. His are really small. *So then do you think this one* [pointing to the smaller beetle] *could be older or younger?* Younger.

Michael: One's bigger. They're different colours. *Why do you think they would be different in size?* Because one's an adult, and one's a [six second pause] larva?

Like Marc, Michael was asked if the larva would have the same physical appearance as the adult beetle. He answered, "no" to this question and to the succeeding question, "So do you think your explanation is correct?" He continued looking at the beetles and pointing out differences in "horns" and leg size. When asked, "Do you think they are both adult beetles?", Michael responded: "Ah-h. Er. Yeah, but [two second pause] um-m [three second pause] no?" To the question, "Do you think one is younger than the other?", he answered, "yeah".

Willie, Danny, John, Scott, Ken, and Cathy were each asked to remember the stage in the beetle's life cycle where it would spend most of the day eating and to think about what had to happen in order for it to grow. They were also asked if the adult beetle would grow once it had emerged from the pupa case and what would need to happen in order for it to do so. Willie and Danny said that the adult beetle can eat and grow because it no longer has an exoskeleton. Its skeleton "would be inside." It was suggested to Willie that gender may be one reason for larger and smaller adults. When he was asked, "Is your mother as tall as your dad? Does she weight as much as your dad?" he answered, "no," and within seconds added, "cause my dad's forty, forty-two, and my mom's twenty nine."

Scott said that the beetle larva had to "molt and do metamorphosis" in order to grow. When asked, "Does the adult beetle grow?" and "Does this 'little baby' beetle look like the 'baby' that comes out of the beetle's egg?", he responded, "n-n-no" and "nope", respectively. His interview progressed as follows:

> McMillan: So if I were to tell you that these were the same age, what would you think?
>
> Scott: Um-m-m-m. Ah-h-h. I think this one [pointing to the smaller beetle] may have just come out of the case.
>
> McMillan: Ok. Does it grow when it comes out of the case?
>
> Scott: Um-m. A little bit?
>
> McMillan: Well, it's going to be able to eat, but it's not going to be able to molt, is it?
>
> Scott: Or grow.
>
> McMillan. So why do you think, then, if these are the same age, that one is so much larger than the other one?
>
> Scott: Um. Because it was born before? No. Ah-h-h. It molted more? Ah-h-h. It came out of its case before? Ah-h. It ate more.
>
> McMillan: When? When in its life did it eat more?
>
> Scott: As a larva.
>
> McMillan: So if it ate a lot more, is it going to have a larger pupa [interrupted]

Scott: Yeah.

McMillan: and make a large adult?

Scott: Yep.

McMillan: Ok. [The interview continues with a discussion of the relationship of gender to size in the animal kingdom.]

McMillan: So now if you see two ladybugs, and one's big and one's small, will you say, "Oh, the small one is the baby"?

Scott: Um-hum.

Ken and Cathy were told that insects as adults don't molt. They don't grow as the larva does. Having heard this, Ken was asked if he thought the smaller of a pinned adult beetle pair would be younger than the other. He said: "No. Because after it's adult, it doesn't grow anymore." When he was asked why he thought some are bigger and some are smaller when they are of the same kind, he answered: "Um-m, be-ecause, they're not born at the same time?"

In addition to the information on larva and adult growth, Cathy was told that some insects are born without mouth parts. Their life span is so short, there is only time to mate and lay eggs before dying. At this point in her interview, she was asked, " So if you think about it, is it possible that these big and little beetles could be different ages?" Her response and the next minute of her interview are excerpt below.

Cathy: Ah, yeah.

McMillan: How could it be though? How could this one grow to that size, or this one to that size when they're all adults?

Cathy: Oh! They're all adults!

McMillan: Well, do they look like pupa?

Cathy: No.

McMillan: Do they look like larva?

Cathy: No.

John said that during the larva stage, the insect spends its time "eating and growing, eating and growing", and that the mealworm larva was "worm-like". He also agreed that the little beetle looked more like a small adult than a larva. His response to the subsequent question, "So if I were to tell you that these were both adult insects, why do you think then that one is so much larger than the other?" was: "Because that's the baby and that's the adult". He was then asked if his mother was the same size as his father, and it was suggested to him that the sizes of the adult beetles may be related to one of the beetles in each pair being a female and the other being a male. He pointed to one that he thought might be the male, saying: "Yeah, and that's the dad." The interview ended with the following exchange:

> McMillan: You're right. That's the male. So all of these are adults
>
> John: Um-hum.
>
> McMillan: and they will never get bigger. So even though this is small, it's an adult.
>
> John: Cause all of these are dead.

CHAPTER SIX

CONCEPTUAL MODELS AND PERSON ANALOGY IN CHILDREN'S CONSTRUCTION OF SCIENTIFIC BIOLOGICAL KNOWLEDGE

As a teacher, my mind is filled with images of the year nineteen children tried to help me understand what it means to learn in school science. I wonder to what degree the writing about the life science unit in the previous chapters captures what was happening in Lauren's classroom. As a curriculum developer my mind is filled with notions of conceptual models, children's "everyday science", and the nature of science. At one moment, I wonder if the organization of a curriculum and the sequence of lessons it generates has a productive bearing on the components and the relationships between these components that conceptual models are thought to be in long term memory. At another moment, I wonder how literally one should interpret the view that an understanding of the learner's current knowledge is the most appropriate starting point for instruction. As a researcher, my mind is filled with thoughts that are simultaneously enthused and uncertain. The doubt I feel is not a problem of knowing what to say; the data reported resonate with possibilities. It is rather a difficulty brought about by perspective and language. As far as perspective is concerned, I wonder if the conclusions drawn will be those that any attentive reader would induce, or has my particular way of looking at the lessons and interview data limited my perception? Language is problematic because in a few pithy statements it can make something sound so clear and simple and obvious that in reality could not be more complex. That which makes the teaching of young children intriguing, in all meanings of this word (*i.e.* fascinating, engaging, interesting, pleasantly puzzling, and the like), is at the same time that which can make qualitative studies perplexing. That being said, I will begin with a discussion of the thinking the interview data suggest the envisioned and enacted curricula occasioned. The results will then be interpreted through Inagaki's claim that everyday biology can be elaborated and incorporated into scientific biological knowledge (1990a). The conclusions drawn from these two analyses will be used to propose life science concepts and age-correlated weaknesses in thinking that Howe (1993) and Metz (1997), respectively, have invited researchers to identify. I will conclude with a discussion of what the data suggest with respect to literature-based science instruction, interest, the modeling of productive questioning, and the kinds of initiating activities and lessons that should precede the planning and execution of school-based archival and laboratory investigations that originate in the questions of the learner.

PRE-INSTRUCTION CONCEPTIONS

Like Metz (1997) and the authors of *Benchmarks for Scientific Literacy* (AAAS, 1993), I am interested in reporting what can be learned from effective instruction. For this reason, it's important to understand that the classroom in which I worked was multi-age (Grades 1, 2 and 3), and that the outcomes the life science unit attempted to help the children achieve included those in the *Science:Grade 3 Guide* (1991a, Manitoba Education and Training). The life science units in the provincial science curricula, Kindergarten through Grade 6 (more than those in either the physical-chemical science "theme" or earth-space science "theme") are spiraled. That is, as Bruner suggested in *The Process of Education*, the curriculum revisits basic ideas, in progressively more complex forms, in an attempt to deepen one's understanding (pp. 12-13).

The red thread (basic ideas) running through the first seven years of formal schooling is the interdependency and interaction among organisms. It begins in Kindergarten with plants as objects that are living and, unlike nonliving objects, require "certain things to grow" (Manitoba Education and Training, 1991b). In Grade 1, children are helped to realize that "people are living organisms (animals/mammals)" with needs and common physical characteristics that vary to make each individual unique and uniquely human. The children also become acquainted with the distinctive features and needs of six common groupings of animals (*i.e.*: mammals, insects, birds, amphibians, reptiles and fish) (Manitoba Education and Training, 1991c). Plants and animals are reintroduced in Grade 2. The focus, initially, is observable properties/characteristics and their use in classification schemes. Later the children are helped to see that the same properties and characteristics are the factors which give a plant or an animal an advantage in a particular habitat and thereby determine the location in which it is most likely to be found in the environment (Manitoba Education and Training, 1991d). Grade 3 exposes children to the life cycles of animals, particularly the amphibians and insects that undergo metamorphosis, and introduces observable animal behaviours that are instinctual and need not be learned (Manitoba Education and Training, 1991a). Plants and animals reappear in Grade 4 as populations occupying a particular habitat. Children become acquainted with the ecological notion of community as interdependent populations of plants and animals each occupying a specific niche with respect to the transfer of food energy (*i.e.*: food webs, food chains, predator-prey relationships) (Manitoba Education and Training, 1991e). In Grade 5, the physical properties and characteristics of plants and animals introduced in Grade 2 and the stages in the life cycles of animals introduced in Grade 3 are reinterpreted in the context of structural and behavioural adaptations (Manitoba Education and Training, 1991f). Population interactions are revisited in Grade 6. The transfer of food energy becomes the flow of energy in an ecosystem from sunlight to primary producers to first, second, and third level consumers to decomposers. The focus is competition, population density, humans as consumers, and the consequences of abiotic factors (*e.g.*: soil, water, air,) on survival (Manitoba Education and Training, 1991g).

In multi-age classrooms, like those of Lauren and Cecile, where the science curricula of the grade levels are cycled through (each child at the end of three years will have been exposed to the content now mandated for Grade 1, Grade 2, and Grade 3), a spiraling curriculum becomes problematic. One of the three groups of children will encounter the concepts in the sequence in which they were designed, assuming, of course, that science is a part of a child's early years school experience. In Lauren's class, this happened to be the six children in Grade 3. The seven children in Grade 2 would have encountered the Grade 2 science curriculum in Grade 1. The seven children in Grade 1 would begin the life cycles unit with personal knowledge of the life sustaining needs of humans and no formal instruction in the classification of animals or plants. Like many events that surface each day in formal schooling, this particular circumstance was not considered an impediment. It was one of the reasons the curriculum envisioned in the pre-planning stage focused upon patterns, an important strand in the mathematics curriculum, and cycles. Rather than knowledge of specific science content, children could draw upon their intuitive and, in some cases, tutored knowledge of pattern, and life cycles would be learned as patterns (sequences) of change that happen over and over again. However successful this particular conceptualization may have been, the field notes alluded to the difficulty associated with the design of the lessons as benchmark-invention, elaboration, and enlargement when the elaboration activity was one that the children regarded as benchmark-invention (see Monday 30 September).

If it is true, as Glynn and Duit claim, that mental models and conceptual models coexist in long term memory (*cf.* Pines and West's (1986) vine metaphor and Solomon's (1983) thinking in two domains) and formal schooling is to help learners "activate the appropriate model in the appropriate context" (1995, pp. 21-22), then cumulative records of the thinking made explicit in specific contexts should be evidence not only of what has been learned but also of the conceptual models being developed. For this classroom-based study, the ideas expressed during the pre-and post-instruction interviews and science lessons are the data from which children's learning and the incipient conceptual models of life cycles can begin to be disclosed.

QUESTIONS 8 AND 9

All fifteen of the children interviewed in early September said that they had seen an adult frog. Seven of these fifteen (Willie, Debbie, Anne and Cindy in Grade 1 and Cathy, Marc and Michael in Grade 3) knew that the frog before becoming the frog was a tadpole, seven (Danny in Grade 1, Sarah, Ken, Robert, and Scott in Grade 2, and Annie in Grade 3) believed that it would begin its life looking like a small or little adult frog, and one (Reena, Grade 2) didn't know about baby frogs.

When asked about the butterfly's life cycle, eleven of the children knew that a caterpillar (the larva stage) became a butterfly or moth and six described the pupa case ("canoe", Willie, Grade 1; "nest", Debbie, Grade 1; "raccoon egg", John, Grade 1; "cocoon", Cindy, Grade 1; "raccoon", Sara, Grade 2; "little nest thing", Cathy, Grade3). Of the remaining four, one child believed that the caterpillar would grow during its life and get a lot bigger (Danny, Grade 1), another said that a little moth emerged from a butterfly egg (Anne, Grade 1), and two didn't know (Ken, Grade 2 and Annie, Grade 3). It is important to mention that the interview question changed in the latter three instances. Rather than being asked, "What happens to a caterpillar as it gets older?" or "What does it become?", Anne, Ken and Annie were asked, "What does a butterfly look like when it emerges from an egg?" or "Do you think that when the butterfly hatches out of an egg that it's just a tiny butterfly that grows and gets bigger?" They may very well have know that a butterfly larva becomes transformed and does not end its life in the form in which it began.

Two of six children asked about the growth of the adult butterfly said that it would grow "a little bit" (Scott, Grade 2 and Michael, Grade 3). Of the four who thought that it would not grow, two children believed that this would not hold true for wasps (Willie, Grade 1) or flies which not only increased in size like the wasps, but also became bumblebees (Sara, Grade 2).

QUESTIONS 5, 6, AND 7

The fourteen children growing up with pets and livestock generally described the changes with age in terms of size (getting bigger, taller, wider, fatter) The descriptions did not differ from the changes in height mentioned about their own growth. When they were asked if it would be possible for baby animals to remain baby animals, only one of the twelve children responding thought that it was (Robert, Grade 2). When asked what happens when a baby brother or baby sister gets older, Robert replied, "They change, because they get bigger feet, a-a-ah, they get bigger arms, they get bigger hair."

QUESTION 10

Three of eleven children believed that a lamb (Robert, Grade 2), cat (Ken, Grade 2), and a cat and a puppy (Willie, Grade 1) changed more in a lifetime than a butterfly. One child thought that a cat would change as much (Debbie, Grade 1). Of the seven who said a caterpillar or frog changed more than a kitten or puppy of fish, two children suggested a person (Sara, Grade 2) and a shark or whale (Marc, Grade 3) as examples of animals that change with age as much as the butterfly and frog. It should be mentioned that Ken answered Question 10 without knowing the life cycle of the butterfly. He also suggested that a fly would change more than a cat, but the changes he spoke about were not associated with transformations in appearance. They were the changes that such a "pest" provokes in the lives of humans.

In view of the literature on children's conceptions of growth in animals, the data substantiate what has been reported. Inagaki and Hatano (1987) found that by the age of six, children understood that growth for living things is inevitable. Rosengren, Gelman, Kalish, and McCormick (1991) used small, medium and large photographic reproductions of animals in a study of real life transformations. They reported that children as young as age three "do not expect animals to be unchanging over time", "realize that growth in animals entails a change in size", and "expect that the young of a species will closely resemble the adult of that same species in color and shape" (pp. 1311 and 1318). Carey's (1985) work with pre-school aged children and Okeke and Wood-Robinson's (1980) study of Nigerian students between the ages of sixteen and eighteen showed that growth was, in general, observational and defined as getting bigger.

If the conclusions cited above reflect the reality of children's biological knowledge, it is reasonable that a child would equate dramatic changes in size with fundamental morphological changes involving metamorphosis. They both bring about striking changes in appearance.

Without exposure to the idea of metamorphosis, one would expect a child to believe that a small version of an adult emerges from an egg and that a caterpillar increases in size with age. Similarly, one would expect the adult insect to grow. It is only knowledge of insect life cycles and exoskeletons that allows one to believe otherwise. Such explanations are based upon what Carey (1985) refers to as the comparison-to-people model and what Inagaki (1990) calls person analogies for non-human animate objects. Each involves the transfer of knowledge about humans to less familiar or unfamiliar objects and organisms. Striking examples of this transfer can be found in Russell and Watt's (1990) report on growth. In this study, primary school aged children were asked to draw what they would see if the shell of a fertilized chicken egg was transparent. The largest group of children drew fully formed (structurally complete) but miniature chicks that increased in size during incubation (pp. 28, 31). Others drew the chick, as we know it upon hatching, sitting in the egg in a state of limbo for twenty-one days (p. 10). The fact that four of the six Grade 1 children in the present study mentioned the larva, pupa, and adult stages in the life cycle of the butterfly suggests that they either observed the process as Cindy had, read about it as Debbie had, or acquired this information through other oral, written or pictorial forms. The same inference can be made for the knowledge of tadpoles and frogs and for the children in Grades 2 and 3.

THE EXPERIENCED CURRICULUM: DEVELOPING CONCEPTIONS

Regardless of the unit, instruction in school science often begins with the activity suggested for the first objective or outcome listed in the science curriculum document or, in this particular province, the first activity in *Hands-On Science*, a popular and locally developed teacher resource aligned with the science curriculum. Attempts are seldom made to elicit the ideas and beliefs underpinning each child's everyday science, and science lessons are more often focused on covering content than developing an understanding and sense of wonder about the natural world. This is perhaps as much a consequence of the roles, other than the one of teacher, that men and women in this profession have gradually assumed (Groves, 1995), as it is the prescribed curricula for each school subject. While the arguments for and against curricula mandated by government are beyond the scope of this study, the contents and expectations are not.

What should have become obvious in Chapter Five is the amount of time learning-centered approaches to science teaching require, and the unscheduled circumstances and events that can consume not only the minutes set aside for science lessons but entire school days. In late August, Cecile and Lauren had planned for the life cycles unit to extend over nine weeks from the 9th of September to the 8th of November. When we met after school on the 16th of October to discuss upcoming lessons, seven sessions remained, one of which was to be the presentation by graduate students from the entomology department. We had not begun to introduce the children to the concepts in the curriculum document, and the three of us recognized that every week utilized for the life sciences beyond the 8th meant less time for helping the children to achieve the eighty-six objectives in the four remaining units (*i.e.* Energy, Heat, and Temperature; Changes in Matter, Air and Air Pressure; and The Earth, Sun, and Moon) (Manitoba Education and Training, 1991a). Cecile had every right to be concerned. We all were. Lauren, however, had become my advocate. Her attempts to help the children distinguish between the concepts "living" and "nonliving" had shown her what Duckworth meant when she wrote:

> Teachers are often, and understandably, impatient for their students to develop clear and adequate ideas. But putting ideas in relation to each other is not a simple job. It is confusing; and that confusion does take time...if we are to build the breadth and depth that give significance to our knowledge (1987, p. 82).

It is not simply that too many units per grade level exist, and that the outcomes for each are excessive, given the adopted strategies. A greater problem resides in the disparateness of the units that make up a year of school science, and the difficulty of establishing even the semblance of coherence from one to the next. Using the Grade 3 curriculum as the example, one wonders which unit should follow a study of life cycles. Should it be an exploration of Earth-Sun and

Earth-Sun-Moon relationships? The properties of air and the effects of air pressure? Investigations of heat energy, heat transfer and the measurement of the hotness and coldness of an object? The characteristics and particulate nature of matter, suspensions, solutions, and mixtures?

In many classrooms, a unit begins, comes to an end and is shelved. What has been learned is not seen as being useful for what is to be learned. Children should know, as Glynn and Duit maintain, that they are in the domain of physics or biology or geology so that they can "activate their conceptual models and 'think like physicists'" or biologists or geologists (1995, p. 22), but this does not imply that there are no relationships constructed between the concepts of each discipline. The conceptual models teachers help children to construct in school science should be more like a food web than several discrete food chains. This is the principal reason for patterns and cycles featuring so prominently in the lessons that began the school year. They were the red threads (Bruner's basic ideas) that would flow through the next nine months of science providing the coherence that is as important for learning as is revisiting natural phenomena in progressively more complex forms. This is what Resnick and Klopfer allude to when they write, "[f]or key concepts and organizing structures to become generative, they have to be called upon over and over again as ways to link, interpret, and explain new information" (1989, p. 5).

Key concepts, guiding principles, and organizing structures (conceptual models) are often perceived as being less important than the skills and strategies necessary for posing and solving questions when inquiry approaches are used to learn science. All of the reasons for scaffolding, presenting ideas in advance of development (Bruner, 1983), benchmark instruction (Hunt and Minstrell, 1994), and invention (Karplus, 1964b; Karplus and Thier, 1967) are dismissed or overlooked. It is as if the construction of scientific knowledge is commonsensical or sense making, when it is neither (see Chapter Three). Excerpts from the writing of Wolpert, on the unnatural nature of science, and Hodson, on learning science, help to again make this clear:

> ...the world just is not constructed on a common-sensical basis. This means that 'natural' thinking – ordinary, day-to-day common sense – will never give an understanding about the nature of science. Scientific

> ideas are, with rare exceptions, counter-intuitive: they cannot be acquired by simple inspection of phenomena and are often outside everyday experience (Wolpert, 1993, p. *xi-xii*).
>
> …it matters very much what kind of understanding students acquire. Learning science is not simply a matter of "making sense of the world" in whatever terms or for whatever reasons satisfy the learner. Rather, it involves introduction into the world of concepts, ideas, understandings and theories that scientists have developed and accumulated (that is, *what* science knows) (Hodson, 1999, pp. 241-242).

The benchmark-invention lessons in the life cycles unit were designed to introduce children to the world to which Hodson refers. The concepts focused on included the following: sett, pattern, cycle, change, model, animal, lifetime, birth, living, death, life cycle, adult, baby, hatchling, metamorphosis, egg, tadpole, insect, exoskeleton, nymph, larva, pupa, cocoon, chrysalis, case, molt, and social insect. Patterns, composed of repeating setts, had a beginning and an end. They could be found in the natural world (branching of trees, veins of leaves, honeycombs, fronds of ferns, webs of orb spiders, and the like) and human constructions (clothing, quilts, stories, songs, the components of buildings, fencing, playground structures, sidewalks, mathematics, and the like). Cycles were repeating patterns. They happened over and over again and, like a circle, had no apparent beginning or end. They could also be found in human constructions (school day cycle, hours in a day, days in week, months in a year, traffic signals, and the like) and the natural world (heart beats/pulse, day and night, phases of the moon, cycle of the seasons, the life cycles of plants and animals, and the like). Although the lifetimes of all animals included a beginning (birth) and an ending (death) with living in between (Mellonie and Ingpen (1983), not all animals began life after birth in the form in which they would end it. Those born as smaller versions (morphologically) of their adult parents included the mammals, reptiles, fish, and birds. The animals born with a form and structure unlike the adult parent included the amphibians (frogs and toads) with egg, tadpole and adult stages in their life cycles and insects with egg, larva, pupa, and adult stages (butterflies, moths, honeybees, ants, mosquitoes, and ladybeetles). Each child's conceptual model would be constructed from concepts introduced in benchmark-invention lessons and the relationships between the concepts that the children established as new information was discussed, interpreted, questioned, elaborated (through dramatizations, drawing and writing), and refined.

POST-INSTRUCTION CONCEPTIONS

QUESTION 5

The seven children in September who believed that a little frog would emerge from a frog egg, and Reena, who said that she didn't know about baby frogs, had no difficulty talking about the transition from egg to tadpole to adult. With the exception of John who mentioned the appearance of front legs before the hind legs emerged, the responses of thirteen of the fourteen children interviewed were similar to Danny's who said: "First it is an egg. Then it's a tadpole. Then it gets the back legs. Then the front legs. And then it's developing his long tongue so he eats his tail. Then he's a young adult. And then he turns to adult."

Of the eight children who named or talked about the tadpole during the pre-instruction interview, only Debbie's retelling differed ("egg, larva, pupa, adult"). She was not asked to discuss the frog's life cycle but to talk about what she believed the life cycle of another amphibian, the salamander, would be. It was not until it was suggested that she try to remember the three-dimensional models of the frog's life cycle that she responded, "Oh yeah! Um. Um. Egg [three second pause]. Tadpole [three second pause]. Youth." and began talking about gills and becoming more frog-like. The other children, when asked the question Debbie had been asked, believed that the salamander emerged from the egg as "a smaller version than the mom" (Danny), as a tadpole with legs (Willie, Scott, Ken, Annie, Cathy and Marc), or as a tadpole that would develop legs (John, Reena, Sara, and Michael). Cindy (Grade I) said that she didn't know.

QUESTION 4

When asked about the life cycle of the snake, turtle or lizard, Willie and Debbie gave responses similar to the answer given by Marc who replied, "The turtle, um-m, it goes from e-eg-g, and then egg, and then a baby turtle, and then an adult turtle." This was eventually the answer provided by the other children when it was suggested that they think of the three-dimensional models used to illustrate the life cycles of the snake and the tortoise. The transfer of this knowledge to the lizard was problematic for Cindy, Sara and Cathy. Cindy thought that the life cycle could be, "egg... larva?", but then said that she couldn't remember. Sara believed that it would be egg, larva, pupa, adult. Cathy had to be reminded of the models a second time when she realized that it wasn't either egg, adult or egg, pupa.

In their descriptions of the reptile hatchling, six of the children (Anne, Debbie, John, Reena, Sara, and Marc) said that it would look like the mother, or be a smaller version of the mother. No mention was made of the father. One possible explanation is the importance of the mother as caregiver in the lives of many young children. This, I suspect, is the reason Willie asked why the mother snail didn't take the snail egg away from the marauding centipede in Coldrey's book, *Snails*. There is also the possibility that the relationship of the hatchling's appearance to the mother's appearance was an expression of the children's beliefs about inherited characteristics. Kargbo, Hobbs, and Erickson (1980) reported that a large number of children between the ages of seven and thirteen thought that "the mother would contribute more to the genetic make-up of the offspring than the father" (p. 142) because "she gave birth to the babies" and "has the most contact" (p. 143). According to Wood-Robinson (1995), this is a belief held by many learners. He suggests that the equal contribution of two parents in the genotype of their offspring "runs counter to everyday experience" (p. 122).

QUESTION 7

All fourteen children arranged the drawings of the stages in the mealworm's life cycle in the proper sequence, and thirteen used the proper terminology in naming the four stages. Anne, who in September believed that a little moth would emerge for the egg of a butterfly, referred to the larva, that "eats and grows" as the nymph. She couldn't recall the correct term and selected nymph when larva and nymph were suggested as possibilities. Danny, who in the pre-instruction interview said that a caterpillar would grow bigger and bigger as it aged, not only placed the drawings in the order egg, larva, pupa, adult, but spoke readily about the life cycle of the lady beetle, another insect that undergoes complete metamorphosis. When asked about the lady beetle larva, he responded: "It, sheds its skin and eats and grows. And then his skin, his exoskeleton gets too tight, so he sheds it, and then, molts it, and then he goes, and then he, he's a pupa. He eats and grows and then he has a case and then he comes out of the case and then a ladybug adult."

All of the children, like Anne and Danny, understood that the larva was the stage in an insect's lifetime where eating and growing and shedding/molting of the exoskeleton occurred. The pupa state was defined with less unanimity. The children believed that the mealworm pupa would make a case and rest and change into the adult beetle, but Reena, Annie, and Cathy suggested that the resting involved growing. With hindsight it would have been advantageous to ask more children than Marc the question about the pupa eating while resting. That is, is growth associated with an increase in mass or a change in form and structure (*e.g.*: the insect "grows" wings and "grows" antennae)?

A relationship constructed by four of the children (John, Scott, Reena, and Marc) and made explicit in their descriptions of the mealworm larva was one being established between the elongated form of the larva (worm-like in appearance) and the shape of the lady beetle larva (lizard-like in appearance) learned about in class. Both had a "long tail". Willie also spoke about the tail but associated it with an aquatic habitat and a structure necessary for swimming. It would have been useful to know if this correspondence was a consequence of knowing about amphibians and/or having been shown images of the dragonfly naiad and the mosquito "wiggler". In either case, it represents what Inagaki (1989) has labeled "similarity-based attribution." She draws a distinction between this form of attribution based on specific observable properties and "category-based attribution" which she defines as "deductive attribution arrived at by relying on higher-order category membership and category attribute associations" (p. 80). If I had been aware of her paper during the life cycles unit, the post-instruction interviews could possibly have had a different character. I was interested in children applying the biological knowledge they had learned through lessons focused on the life cycles of the turtle, snake, frog, grasshopper, cricket, butterfly, honey bee, ant, mosquito, dragonfly, and lady beetle to animals not discussed in lessons (*cf.* "experiencing formal knowledge in use", Schrag, 1992, p. 284). In many cases, the category was given, either directly or with explicit hints. This was believed to be necessary as the focus was a child's understanding of life cycles, not his or her ability to classify a particular animal. In so doing, an association may not have been made, and the child may simply have talked about the life cycle of the known animal. This is certainly one way of interpreting Anne's "it loses his tail" and Reena's "[it] eats its tail" and Cathy's self corrected "they, da, lose their tail" when using knowledge of the frog to speak about the salamander.

QUESTION 6

The illustration of the life cycle of the grasshopper, in which a pupa state (the chrysalis of a butterfly) had been inserted, generated three different interpretations. Debbie, Sara, and Ken believed that it was an accurate representation of the egg, larva, pupa, and adult stages that the grasshopper would pass through in a lifetime. Anne, Danny, John and Annie described the chrysalis as old skin or a discarded exoskeleton. Willie, Cindy, Reena, Scott, Cathy, Marc and Michael identified the chrysalis as a "pupa" (or "chrysalis" in the case of Cathy) that Willie, Reena, Scott, Cathy, and Marc said did not belong in the life cycle of the grasshopper or the cricket.

On the surface, it appears that eleven of the children understood that the grasshopper/cricket was an insect with a three stage life cycle. It emerged from the egg resembling the winged adult it would eventually become by eating and growing and molting. Six of these eleven children referred to the immature grasshopper/cricket as a "nymph". Two children identified it as a "young" or "not fully grown" grasshopper/cricket which is the meaning one would infer from Anne's and Danny's "cricket" – it was not an "adult" cricket. Two of the children called it a "larva", though John sensed this was not the proper term to use. My apprehension, with the above interpretation of the responses of these eleven children, is that the illustration may actually have been viewed by all but five of the fourteen children as being an accurate representation of the grasshopper's life cycle, rather than a flawed representation of incomplete metamorphosis. Anne, Danny, John, Cindy, Reena, and Annie in one group, and Debbie, Ken, and Sara in another simply talked about what they saw in the drawing whose accuracy they had been asked to judge. They didn't think through the knowledge their interpretations were based on. How else does one explain the fact that the chrysalis was identified as "old skin" or an "exoskeleton" being shed when the skin or exoskeleton did not resemble in any way the form and structure of the grasshopper's body. It was a drawing of the pupa of a caterpillar as Cindy and Mark and Cathy supposed. Whether a consequence of the illustration and questions posed or a deliberate and thoughtful attempt to explain an anomalous object, the responses to Question 6 say more about Anne's, Danny's, John's, and Annie's understandings of molting than incomplete metamorphosis. The same can not be said of Debbie's, Ken's and Sara's responses.

These three children saw four images, and immediately thought, egg, larva, pupa, adult and little more. They either failed to recognize that the grasshopper that emerged from the egg did not have to rest and undergo metamorphosis to achieve its adult form, or Debbie and Sara, like Ken who believed the "artist" had not included a drawing of the nymph, did not understand that the larva requires a pupa state because, in terms of gross morphology, it looks nothing like the adult it will one day be. One has evolved as a consumer, the other has evolved to disperse and reproduce.

QUESTION 2

Twelve of the fourteen children responding to post-instruction interview question #2 displayed an understanding of sett, pattern, and cycle. They were able to identify and repeat a sett in a pattern and convert a pattern, with a beginning and ending, into a cycle. Two of the children found these activities problematical. When asked to identify one sett in a two sett pattern, Anne said that the pattern was the sett. She did, however, repeat the sett, when asked to do so, but did not put the three sett pattern into a cycle in spite of the fact that she had defined a cycle as "a pattern that keeps on repeating". Danny identified as the sett each unique animal or animal group making up a sett. Like Anne, he repeated the sett by "copying" one of the two in the established pattern. When he linked these to form a cycle, the sequence was altered and the circle created did not become a repeating pattern. He said that a cycle was "when there's a sett, and it doesn't ever stop".

The inability to successfully perform what had been requested in two of the three tasks seems to have had little if any impact on Anne's and Danny's understanding of lifetimes and life cycles. All of the children could talk about animals and the lifetimes of specific animals in a language and with a breadth and depth of understanding that was not evident in September. One conclusion to draw is that although underdeveloped, the network of inferences that Black and Harlen (1993) discussed (see Chapter 2, Mental and Conceptual Models) as being "too often" vague and fragmented, are, for the fourteen children represented here, on their way to becoming organized in a manner that will enable the categorization of organisms and events as examples of particular life cycle concepts.

As the science teacher, curriculum developer, and researcher in this study, I can't help but wonder if the perceived need for continuity in school science was misguided. Perhaps the time spent developing the basic ideas of pattern and cycle would have been better used developing formal and procedural biological knowledge. This is a question that analyses of the data gathered in the present study can't answer. The fact that the lessons and instructional strategies, by which a teacher engages students, have been shown to influence the development of scientifically valid conceptual models suggests that a longer-range coherence would be to a student's advantage. One simply must determine if the immediate expenditure of the limited instructional time in school science is worth the potential long term gain.

EVERYDAY BIOLOGY AND SCIENTIFIC BIOLOGICAL KNOWLEDGE

Everyday biology is defined by Inagaki (1990a) as "informal biology acquired through everyday life experience" (p. 281). It represents one discipline of everyday science which is one division of everyday cognition – the body of procedural and conceptual knowledge acquired without any systematic teaching-learning (Hatano, 1990).

According to Hatano (1990), Carey's (1985) comparison-to-people model and Inagaki and Hatano's (1991) constrained person analogy may represent the earliest forms of everyday biology (concepts and a set of innate and early constraints) that make spontaneously constructed concepts possible and reasonable. Learners take what they know about humans and generate predictions for other non-human animate objects, and they check the plausibility of their inferences with the knowledge they possess about the target objects (Inagaki, 1990a). Inagaki's (1990b) studies of children raising goldfish suggest that domains in which a child has rich conceptual knowledge may also be utilized as sources for making analogies. The person analogy, however, appears to be the "basic 'fall-back' strategy for children" (Inagaki and Hatano, 1991, p. 230).

When the responses to Question 4 in the pre-instruction interview are read with the constrained person analogy in mind, the children's predictions make perfect sense. The target object in the scenario is an oak tree. Children recognize that as a human grows and increases in height it is not simply the legs that elongate or the neck that is stretched upward or the torso that lengthens. Every body part appears to enlarge and to move upward but in so doing maintains its relative position with respect to all other body parts. Using the person analogy, a nail forced into a tree at a height of approximately 1.0-meter would have moved upward in ten to twelve years, as fourteen of the fifteen children suggested. Only Annie believed that the nail would stay in the same place, because she said "the nail won't grow." Like Ken, she realized that the nail would stay in the same position relative to the tree. The question, however, asked where the nail would be relative to her position as the observer.

Inagaki refers to responses such as these as "overattribution errors" (1989, p. 86). Attribution errors are generally a consequence of limited biological knowledge – the learner has no way of checking the plausibility of his or her inference. In the case of the oak tree, growth does not occur as it does in humans. Cell division is localized and occurs in the apical, primary elongating, and lateral meristems located in the tip (apex) of the shoot and the root, in a region below the apical meristem, and in an area behind the bark, respectively. There is a very good likelihood that the lateral meristems that bring about an increase in girth will have begun to cover over the nail in ten to twelve year time-span. The position of the nail relative to its distance from the ground would not have increased perceptively.

Inagaki claims that biology has a "relatively privileged position" among the everyday sciences owing to its success for inducing correct or nearly correct answers (1990a, p. 287). The conclusion she reached is that everyday biology can be elaborated and incorporated into scientific biological knowledge without replacing the former with the latter" (p. 286). Given the previous responses and the children's answers to Question 8 in the post-instruction interview, I would suggest that the constrained person analogy can hinder and act as an obstacle in the learning of biological knowledge. This is a circumstance where children would be better advised to do as Floden, Buchmann, and Schwille recommended and "break with their everyday experience in thought" (1987, p. 485), if such "breaking" is possible for young children.

With the exception of Marc who attributed the difference in size of the paired adult beetles in Question 8 to a difference in gender, the children believed that the smaller beetle in each pair was a younger beetle. Even Marc, when asked if the beetles could be the same age, responded, "...that could be the adult and that one could be the [two second pause] um-m-m littler one." By "littler one," he meant larva. This view was tenaciously held as the excerpts from Willie's, Scott's, Ken's, and John's interviews reveal.

Willie, like Danny, believed that an adult insect had an internal skeleton that would enable it to grow without the need to molt. When it was suggested to Willie that the difference in size could possibly be the result of gender, he agreed that his mother was smaller than his father but quickly added that his father was forty-two while his mother was twenty-nine – thirteen years younger.

Scott understood that a beetle larva would not resemble the adult, and he said that the adult beetle could not grow in size. With this knowledge, he worked through possible explanations for one beetle of each pair being larger, dismissed them, and finally suggested that it ate more as a larva. After talking together about the relationship of gender to size, another probable explanation, he admitted that if he saw two labybugs, one small and one large, he would say the small one was the baby.

Ken was helped to realize that adult insects can't eat and grow like the larva that molts. His explanation for the unequal size of the beetle pairs was that they were not born at the same time. When John was told that the beetles were both adults, a realization that came as a surprise to Cathy, he attributed the size difference to age. One was the baby and one was the adult. He agreed that gender could possibly cause one beetle to be larger than another, but when told that all of the beetles on display were adults that would never get bigger, he attributed this to the fact that they were dead.

As mentioned in the analysis of post-instructional interview Question 7, the person analogy was very likely responsible for children believing that amphibians emerging from eggs would be small versions of the adult. I also suspect it is the reason the children in this study invariably referred to adult animals as "mother"/"mommy" and "father"/"daddy" when female and male were the terms modeled. Perhaps it would have been better, in terms of the biological conceptual models being constructed, to begin the study of life cycles with the animals that produce "newborns" with little resemblance to the adult and not make the comparison to humans explicit. My suspicion is that spontaneous person analogies would have been made anyway. In this respect, I agree with Inagaki who with her colleague Hatano claimed that "young children's knowledge about humans is so immediate that it can easily be retrieved at any moment as a potential source [for predictions]" (1991, p. 230).

RESPONDING TO HOWE'S AND METZ'S INVITATIONS

Howe envisions a theoretical basis upon which the development of science activities for children should occur. She challenges researchers to identify science concepts that children restructure (a) through every day experiences, (b) through appropriate guided experiences, and (c) through analogies, models, mathematical expressions, and other representations that are inaccessible and must be presented (1993, p. 232). Metz looks at "age-correlated weaknesses" in thinking and invites researchers in science education and developmental psychology to develop a research base that distinguishes (a) weaknesses that are robust at a particular stage but readily ameliorated at a subsequent stage, (b) weaknesses that respond in varying degrees to instruction, and (c) weaknesses that constitute an enduring challenge irrespective of age and level of expertise (1997, p. 156). In spite of the different perspective each author's language conveys, it's clear that the purposes are much the same. Metz's research base would enable curriculum developers to recognize those concepts that science teachers should not spend inordinate amounts of time attempting to modify through guided experiences (weaknesses a and c) and those concepts that design tools like those of Lerher and his colleagues' (2000) will help to make more scientifically valid (weakness b).

It is Metz's weakness a that the following comments will address as weaknesses that respond in varying degrees to instruction will have been made obvious in Chapter 5 and in the preceding pages of this chapter. It should be mentioned, however, that the instructional strategies embedded in the enacted curriculum enabled children to realize that an animal gives rise to offspring of a similar kind. This was not a conception that was explicitly taught. During the post-instruction interview (Question 6) one of the seven children who believed that blue jays or hummingbirds or any kind of baby bird might possibly hatch from the eggs laid by the robin (Pre-instruction Interview Question 11) spontaneously said, "A-a-a, I know if, if there's a mother cricket it can't lay, it can't lay a toad."

There are three areas that the data from this study point to as being placed too early in the early years science curriculum. These are the distinctions that children are expected to make between living and nonliving, similarities and differences, and inferences and observations. The responses to Question 1 in the post-instruction interview could not make the difficulty children have with the concepts living and nonliving more explicit. The associations between air, water, food, and the maintenance of life are meaningless, and the knowledge behind the utterances is inert, dead, or whatever term one prefers that implies non-generative. This is made clear in the interview with Danny, though he is by no means unique. Along with Willie, he believed that the potato tuber was living, and suggested that the alien trying to determine whether or not it was a living object would ask if it needs air or food. When Danny was asked if he believed air and food were essential for the potato, he said, "no," it would need water. The potatoes he had at home, however, were not given water, so when he was asked a second time how the alien would decide the potato's status, he answered, "He would check if it needs food and air?"

Driver, Squires, Rushworth, and Wood-Robinson (1994c) in their review of children's ideas about the life concept begin with the research of Piaget. As early as 1929, a progression in the conceptual framework associated with this concept showed that children over the age of eleven would understand that plants and animals are alive. Instruction much before this age, except in cases like Willie's where the child has rich life experiences and the teacher can work in the zone of proximal development, would seem to have little effect in the revision of mental models and the development of biologically valid conceptual models.

Change is often associated with growth and development in the biological sciences and to detect change one must be able to distinguish similarities and differences. Children who have experiences with books and activities that ask them to spot subtle differences between one illustration and another have no difficulty looking for similarities and differences in the context of science. The problem in the life sciences as it becomes transformed in school science is that minute details are seen as being reason enough for a child to suggest that an organism is unlike another. A puppy does not resemble its adult parent, for example, because its colouring is not the same, or a bunny does not look at all like the adult rabbit because it is born without hair. All attempts in this study to focus the youngest children's attention on gross morphology and eventually body parts (*e.g.* legs, wings, eyes, nostrils, and the like) seemed to have limited success as the post-instruction interview (Question 3) with Cindy illustrates. During the pairing task, she placed the illustration of the lamb with the ewe and said, "Ok. Lamb, goes with this. Anyways it kind of doesn't really look the same, because it doesn't have so much fur." Her response suggests that the attention to gross observable features is one she had adopted, somewhat grudgingly, for school. It is an example of Freyberg and Osborne's two perspective outcome: "one view is for living, the other is for examinations" (1985, p. 87) that teachers hope children won't adopt. It may perhaps be to the benefit of learners and teachers alike to wait to discuss "looks like" or "resembles" in Grade 3 or Grade 4.

Observable properties and characteristics of objects, materials, and organisms feature prominently in school science curricula for children. With the demise of the process approach, inferences receive much less attention. They are, however, what children have the least difficulty making and discussing. This was made obvious when the children were asked to think out loud while performing the newborn-adult pairing task in the post-instruction interview. Scott, as one example, spoke about a kitten not jumping as high as a cat, and Robert telling him that a cow gives birth to a calf so that calf is just another word for cow. None of these statements were the result of observing the images on the cards to be sorted. It became a greater problem in the chemistry/physics unit that followed. Several weeks were spent investigating the observable properties of objects (*e.g.* colour, shape, size, mass, texture, hardness, and the like) and using properties to identify objects. During the post-instruction interview for the unit, when the children were given a camera to describe, all discussed the photographs it was used to make. They mentioned, less frequently, the fact that it was an opaque, rectangular prism, gray in colour with a red elastic strap, transparent lens, brittle case, and so on. The distinction between observations and inferences should certainly be modeled in teaching at these grade levels, but drills in the production of one or the other will be fraught with frustration.

LITERATURE-BASED SCIENCE INSTRUCTION

The life cycles unit is not one that I had thought of teaching in the autumn. In a geographical location where snow falls at the end of October, it seemed prudent to set it aside until the spring when plants and animals awaken from their winter dormancy. A warm weather unit also allows for numerous first-hand activities that are not possible if one plans to have children observe the metamorphosis of indigenous species of frogs and insects that will be released into the environment as adults. This was, however, the decision made by Lauren and Cecile, and I decided to work with it and with organisms like the cricket and mealworm available in local pet stores. Not far into the week of interviews in early September, Lauren mentioned that she would prefer not to have live animals in her classroom for what I determined to be ethical reasons – animals are best left in their natural habitats. This meant that what was pre-planned as a investigatory inquiry of animals through time would become a second-hand investigation through literature-based science instruction supported by film, illustrations, and three dimensional models. I viewed it as an opportunity to assess the learning such an approach enables.

In a description of the different forms examples can take in teaching, Eggen and Kauchak claim that realia, "a substitute word for 'the real thing", ... should be used whenever possible" (1996, p. 77). All of the essential characteristics of the concept are illustrated by the real thing, which has the consequence of making the use of pictures, models, case studies, simulations and role play a compromise. Where young children are concerned, and the concepts are, on the whole, observable, it makes little sense not to investigate the real objects, materials and organisms with which the concepts are associated.

My suspicion is that suggestions to the children in the interviews, that they remember the three-dimensional models used in lessons, would not have been necessary if they had been given the opportunity to observe and study living organisms. Annie, for example, when asked about the appearance of insects emerging from eggs, responded that she wasn't sure because she had "never seen a baby insect." She was talking about "the real thing" not illustrations in books or images on video or plastic models.

I also believe that the use of books contributed to invalid conceptions that would not have been identified using conventional forms of assessment, and that the use of dramatization may have simplified the process of insect metamorphosis and, in so doing, influenced the children's understanding in a manner than was not intended.

The text example is one previously mentioned in the context of the developing tadpole (see Chapter 5) . In their responses to the post-instruction interview Question 5, seven children said that the frog eats its tail to make a tongue. The first time I heard this, I was completely taken aback, and became more and more astonished each time it came up. When Marc, the most scientifically astute child said, "Its front legs come, and it develops the lungs, and ah-h-, then it. It makes ah-h. It's making its tongue so it eats its tail and then ah-h-h it's the-e almost the adult and then the adult." I mentioned that he was the fourth person to say that the frog eats its tail, and asked where he had heard this. He answered, "When we were studying science. The frog eats its tail [clears throat] because it can't eat because it's making a [two second pause] long tongue to catch flies. I heard it when we were studying science." I later checked each resource that had been set out for the children during the study of amphibians. I began with the two books that had been read and/or discussed during the lesson on the frog and toad. On page 22 of Chinery's book, *Frog*, I came across the following passage (see Chapter 5, The Enacted Curriculum, Thursday 24 October):

> The tadpole now has all four legs. Its eyes are getting bigger and its mouth is getting wider. A long tongue is growing inside its mouth. The tadpole can't eat anything at this stage, but it won't starve. Its tail slowly shrinks back into its body and this gives the frog the food it needs (1991).

Eating the tail is certainly not the conclusion a biologist would have reached, but it is understandable as the interpretation made by Danny, John, Cindy, Scott, Reena, Marc, and Michael. I am puzzled, however, by the fact that it was not part of the conversation that the text inspired, and wonder what other passages may have motivated interpretations similar in kind.

Dramatization of a life cycle was an elaboration activity that followed the benchmark-invention lessons in which animal lifetimes were introduced. The knit sleeves became props in the enactment of insect life cycles. They were the exoskeletons of the nymph, the exoskeletons of the larva, and the case, cocoon, or chrysalis of the pupa. My suspicion is that the formless and stretchy material of the knit sleeves hindered the children's understanding of the important structural role of the exoskeleton. The struggle to come out of the sleeve may have been real for the children, but it did not simulate the struggle of the nymph or larva to pull itself out of a skin-tight, body cast without hands. This is an event that must be observed first hand and, if it is to be understood, the exoskeleton must be held in the fingers.

Reflections: Interest, Productive Questions, and Initiating Activities

Many educators, including those cited near the end of Chapter 2, believe that curriculum must take account of children's interest, and in some cases build from interests, not just upon them. This is the essence of leading from behind. Unfortunately it's not possible to express an interest in something you know little about, and though one would like to lead from behind, in science it is often necessary to begin by leading/teaching. Exposing children to the world in which scientists live and work does not mean that interests are ignored or that the subject matter must be made interesting to keep each learner engaged. When the discipline comes alive for children in the hands of a skilled and knowledgeable teacher, it is interest that is awakened. This is the interest described by Dewey when he writes about conditions that lie behind and compel it:

> Hence it follows that little can be accomplished by setting up "interest" as an end or a method by itself. Interest is obtained not by thinking about it and consciously aiming at it, *but by considering and aiming at the conditions* that lie back of it, and compel it. If we can discover a child's urgent needs and powers, and if we can supply an environment of materials, appliances, and resources – physical, social and intellectual – to direct their adequate operation, we shall not have to think about interest. It will take care of itself. For the mind will have met with what it needs in order to *be* mind (1913, pp. 95-96).

One expressed form of interest is questioning, particularly the posing of questions Lindfors (1999) describes as "information seeking" and "wondering". Both "arise in what one knows, and in what one is doing with that knowledge" (1999, p. 92). The consequence of this is that one inquires most in areas where expertise is greatest and least where one is most ignorant, because it is knowledge that enables one to sense the possibilities of what lies beyond his or her current understanding (p. 93). What Lindfors' writing suggests is that exploratory activities and brainstorming sessions may not be the best starting points for scientific inquiry. If the children have not previously encountered the concepts in formal instruction, there is a good likelihood that the questions posed will be based on mental, rather than conceptual models, and it is scientifically valid conceptual models that science teachers should aim to help children develop.

When the life cycle lessons began in September, the majority of the questions expressed by the children were information seeking. They asked, for example, Can the snail come out of its shell? Would a snail eat another snail's shell? How are sidewalks made? Are the spaces made in the playground bridge like the spaces made in the sidewalk? Is the corn coloured because it is rotting? Does the snail have a heart? A brain? Arteries? Would an octopus eat snails? Do babies have teeth? Does skin stretch to fit you as you grow? Can a turtle with flippers walk on land?

As they became accustomed to speaking with one another and sharing ideas, and as their knowledge of life cycles grew, the questions began to change. Michael, for example, wondered if it was good for mosquitoes to bite us since they needed blood to lay eggs. We started talking about other animals that the female mosquito might get a blood meal from, and Annie mentioned that mosquitoes bite her horses. She also said that horse flies bother them, and that they shake their heads and the mane on their necks and swish their tails back and forth to keep the flies away. Several days later Lauren pulled me aside to say that Debbie's mother had found her playing on her bed. She had ribbons tied around her torso and waist and was on all fours moving her head and body back and forth so that the ribbons would fly across her back. When her mother asked what she was doing, she replied, "keeping the flies away."

Just before the ant was introduced in late November, Annie asked, "What colours can praying mantids be?" I turned her question around and asked what colours she thought they could be since we had learned that a mantid is a carnivore and hunter. She replied, "They could be green or the colour of a branch or a twig." I used this opportunity to talk about protective colouration, and mentioned that insects coloured with red and yellow and orange hues are warning those who might eat them that "I taste awful." I also said that some insects, which would be quite tasty to a carnivore, mimic these bad tasting animals, and are left alone. During the post-instruction interview, when Annie saw the salamanders, she named them and said, "they're long, and they have the colour that um-m protects them so things won't eat them." This, as well as the episode shared by Debbie's mother, represent examples of what Dewey must have had in mind when he talked about considering and aiming at the conditions that lie back of interest and compel it. These were spontaneous conversations in the classroom, a byproduct of the social and intellectual climate, that resulted in interest and learning that could not have been planned. I have difficulty thinking of more generative ways to initiate scientific inquiry based on children's interests. They were certainly ready with productive questions for both laboratory and archival investigations.

CONCLUDING REMARKS

During the early 1960s, when college-level scientists turned their attention to elementary school science, one of the questions with which they wrestled when developing curricula concerned the role of conceptual models: " Can we teach children science with curriculum materials that have a conceptual structure?" (see page 91). According to Hurd and Gallagher (1967), the question was not one of representing the structures of a discipline, but how best to teach scientific concepts – that is, how to transform "the private wanderings of thought into… what we know and prize as knowledge" (Hawkins, 1970d, p. 66).

It had been recognized by Bruner, Dewey, Gagne, Hawkins, Karplus and Schwab that the origin, quality, kind, and explicitness of input information influenced knowledge change (*cf.* Chinn and Brewer, page 11). This is the reason Karplus maintained that instruction that failed to help children to develop a conceptual framework would lead to invalid generalizations and a haphazardness that would impede later learning (see page 69). It is also the reason Bruner believed that a child's ability to recognize the connections and regularities within materials ("to form increasingly powerful representational systems") depended upon the sequence of instruction and the structure and form of the body of knowledge presented (see page 104).

In the desire to create autonomous learners, many involved in the education of young children have lost sight of the fundamental role that the teacher has in the educational process, particularly in a subject area like science. Accurate description and systematic classification (natural history) have given way to hypotheses and theories that are human constructs produced by creative acts of abstraction, imagination, and invention to explain observations and make precise predictions. Young children have to be introduced to scientific concepts and to the accepted ways of seeing, thinking, formulating questions, supporting knowledge claims, proposing explanations, negotiating meaning, acting and using language in science (see page 10). It may be true, as Short and Burke (see page 29) claim, that "there are no final solutions, only current best solutions", but the best solutions, in school science, are based on scientific, not everyday conceptions and knowledge.

The curriculum designed for the unit in the life sciences helped children to explore new ideas and to construct new knowledge through dialogical interaction, "acts of inquiry", and reflective exploration of multiple sources of information (*i.e.* they were not "bench-bound listener[s]", see page 103). In so doing, the children began to think about the lifetimes of animals in a richer, more sophisticated, and scientifically valid way. The curriculum was framed by the concepts and relationships between concepts that were thought to be necessary in the construction of scientific biological knowledge. This organization did not "fix" what was to be learned, but encouraged the children to think with the ideas presented and, in so doing, to build and refine their conceptual models. These "borrowed", interpreted, modified and continuously refined scientific facts and ideas became the conceptions, preceding sure knowledge, that act to make scientific inquiry (archival and laboratory investigations) fruitful. Unlike the children inquiring about the birds who struggled to record every observation (see pages 27, 31-32), the biological knowledge of life cycles would help the children in this study to formulate questions, to know what to look for, to understand what will and will not pass for data, and the meaning to assign it. It is this understanding, as Schwab explained it, that accounts for "four-fifths of inquiry" in science.

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APPENDICES

APPENDIX A – LETTERS OF CONSENT

LETTER OF CONSENT: PRINCIPAL

_________________, Principal
Maple Hills School
Maple Hills, Manitoba R__ ___

Dear Mr. ____________,

I am studying the teaching and learning of science in early years classrooms and would like your permission to work as a teacher/observer with Lauren ____________, a Grade 1-2-3 teacher in your school, and the nineteen students in her care.

The purpose of the study is to examine the manner in which science, its content, processes, and nature, is represented to the children in Mrs. ____________'s classroom and to document the learning, understanding, and meaning that the children construct and develop as a consequence of carefully planned instructional strategies and carefully developed, conceptually based units.

Data will be collected during my teaching visits to Mrs. ____________'s classroom, through informal and semi-structured interviews with her and the nineteen students, during informal curriculum meetings, and by means of a journal which I have asked her to keep.

The data will be used to fulfill the thesis requirement for a Faculty-based Ph.D. in Education. A summary of the findings will be sent to Mrs. ____________ at the conclusion of the study.

As you know, I have been in weekly contact with Mrs. ____________ for the past several months. She has been made aware of the nature of my research. During our conversations, I have made it quite clear that her right to confidentiality of any personal information collected during the teaching of science, interviews, journal transcriptions, and my participant observation will be maintained and informed her that she has the right to discontinue participation in the study at any time.

Any further information you may require can be obtained by telephoning Dr. Arthur Stinner (474-9068), Dr. Wayne Serebrin (474-9024) - members of my advisory committee, or myself (255-3505 home).

Thank you for your consideration. I look forward to working in Maple Hills School for the duration of the study.

Sincerely,

Barbara A. McMillan

Please indicate your consent by signing in the space indicated below and returning this letter to me.

____
Signature

LETTER OF CONSENT: PARENT/GUARDIAN AND CHILD

Barbara A. McMillan
____
Winnipeg, Manitoba ___ ___

Name of Parent/Guardian
Address of Parent/Guardian
Maple Hills, Manitoba ___ ___

Dear *Parent/Guardian*,

Thank you for accepting the offer, on behalf of your child, to participate in this study. In accordance with the "Policies and Procedures of Ethics Review" established by the Faculty of Education at The University of Manitoba, I am requesting your consent to use the data collected for the study tentatively titled, "The Science Curriculum in Early Years, Multi-age Classrooms."

The purpose of this study is to examine the manner in which science, its content, processes, and nature, is represented to the children in your child's classroom and to document the learning, understanding, and meaning that the children construct and develop as a consequence of carefully planned instructional strategies and collaboratively developed units.

Data will be collected during visits to your child's science classroom and through informal and semi-structured interviews. Classroom events during the science component of your child's curriculum may be video recorded and photographed. As well, the interviews will be audio taped, and occasionally video taped, for transcription.

The information obtained from your *son* (*or daughter*) and *his* (*or her*) classmates will be used to fulfill the thesis requirement for a Faculty-based Ph.D. in Education. A summary of the results will be available upon request after the study is complete and my dissertation has been successfully defended.

With your decision to have *name of child* participate in this study, the data will be kept strictly confidential and will be available only to myself and Mrs. ___________. I would like your permission to use photographic images or excerpts of the student and class audio and video-recordings in publications related to this study. The audio recordings will be transcribed and destroyed with the completion of this research. Participation in the study is voluntary, and your *son* (*or daughter*) may withdraw at any time.

Please indicate your consent by signing in the space indicated below. I also ask that you discuss this study with *name of child* and ask *him* (*or her*) to indicate *his* (*or her*) consent by signing in the space provided below. It would be helpful if you could return this form as soon as possible.

Sincerely,

Barbara A. McMillan

Parent of Guardian Signature

Signature of Child

I appreciate you consideration of this request, and look forward to working with your child in this study.

Appendix B – Manitoba Education and Training Science

Grade 3: Interdependency and Interaction among organisms: Life Cycles

GRADE 3: INTERDEPENDENCY AND INTERACTION AMONG ORGANISMS: LIFE CYCLES

1. A LIFE CYCLE INCLUDES THE SEQUENTIAL CHANGES, IN ORDER, IN THE LIFE OF A LIVING THING
The student should be able to:
a) List the different stages that an organism goes through during its lifetime
b) Define metamorphosis

2i. ANIMALS EXHIBIT LIFE CYCLES (SOME ANIMALS EXHIBIT A COMPLETE METAMORPHOSIS)
The student should be able to:
a) Define and observe a complete metamorphosis
b) Observe that many young animals change completely from their parents

2ii. ANIMALS EXHIBIT LIFE CYCLES (SOME ANIMALS EXHIBIT AN INCOMPLETE METAMORPHOSIS)
The student should be able to:
a) Define incomplete metamorphosis
b) List animals that exhibit an incomplete metamorphosis
c) Infer that these young look much like their parents
d) Observe an incomplete metamorphosis

2iii. ANIMALS EXHIBIT LIFE CYCLES (ANIMALS CAN BE CLASSIFIED ACCORDING TO THEIR METAMORPHOSIS)
The student should be able to:
a) Compare complete and incomplete metamorphosis by their similarities and differences
b) Classify animals into incomplete and complete metamorphoses

3. LIVING THINGS EXHIBIT CERTAIN BEHAVIOURS DURING THEIR LIFE CYCLES
The student should be able to:
a) Define behaviour
b) List some behaviours of animals
c) Observe how the behaviours of animals change in relation to heat, light and water

4. AN INSTINCT IS THE ABILITY TO DO SOMETHING WITHOUT HAVING TO LEARN HOW
The student should be able to:
a) List instincts that animals have
b) Infer that humans do not have the instinct to build nests
c) Classify animals by their instincts to build things, guard their home, migrate, live in groups, prepare for winter, and reproduce

5. HUMANS MUST RESPECT THESE BEHAVIOUR AND INSTINCTS TO ALLOW FOR THE CONTINUITY OF LIFE CYCLES
The student should be able to:
a) Recognize that animals have special behaviours that must be respected by humans
b) Appreciate the adaptive value of some animal behaviours

APPENDIX C – PRE-INSTRUCTION INTERVIEW QUESTIONS

PRE-INSTRUCTION INTERVIEW QUESTIONS

1. Where do you live? (Maple Hills, Eau Claire, Marshfield)
   Do you live in the town of __________ (Maple Hills, Eau Claire, Marshfield) or out on a farm?

2. Does your mother or father have a garden?
   What did you grow in your garden this year? (flowers, vegetables, berries, *etc.*)
   Were you able to help your __________ mother or father) plant the garden in the spring?
   What kinds of things did you help to plant? (seeds or starter plants)

3. Do you have any pets (or animals on your farm)?
   Can you tell me about them?

4. Do you know what I have in this bag? (acorns)
   What do you think would happen to this acorn if we put it in the ground and made certain that it got plenty of water and sunshine?
   Now imagine that you have an oak tree in your yard, and it's about my height when I'm standing. It's a hot, summer day and you decide to have a lemonade sale. So you get together everything that you need and set up in the shade of the oak tree. And, so that people going by will know how much you're charging for a glass of lemonade, you make a sign that shows the price. You get a hammer and nail, and you nail the sign to the oak tree at about your eye level. Now, at the end of the day, when you've sold everything, you clean up. But there's a problem, you can't get the nail out of the tree. You tell your Mother and Father and they say, "Don't worry. The nail won't hurt the tree." So, you leave the nail in the tree. Now, in about ten or twelve years you go back and look at the tree and it's higher than the ceiling (> 3.5 meters). You remember your lemonade sale and wonder where the nail you left in the tree would be. Where do you think you would have to look to find it?

5. Has your _____ (pet: cat, dog, horse, fish, bird, *etc.*) changed as it has gotten older?
   How has it changed?

6. Can you think of other animals, like your _____ (pet: cat, dog, horse, fish, bird, *etc.*), that just seem to get bigger as they get older.

7. Have you changed as you've gotten older?
   What can you do today that you couldn't do when you were a baby?

8. Have you ever seen a frog or a toad?
   What does a baby frog (or toad) look like?

9. Have you ever seen a caterpillar?
   Do you think they change as they get older? (If "yes", ask, How do they change?, if "no", ask, Did you know that a butterfly develops from a caterpillar?)

10. What do you think changes more during its life, a caterpillar that becomes a butterfly/a tadpole that becomes a frog or your ____ (pet: cat, dog, horse, fish, bird, *etc.*)? Explain.

11. Imagine that a bird has built a nest in one of the trees in your yard, and that the bird is a robin. The robin lays five eggs in the nest that she has built in your tree. What do you think will

hatch out of those eggs? (If the answer is "baby birds" or "baby robins" ask the student if it would be possible for the baby birds to be blue jays or hummingbirds.)

12. (Inagaki's question) Show the pictures of the baby animals (chick, penguin, piglet, foal, kitten and human baby) in the book Growing Up. Some people like baby animals so much that they wish they could keep them as babies. Do you think it is possible to keep a kitten a kitten and not have it become an adult cat, a piglet a piglet, or does it have to become a pig, and so on. Why do you believe this is possible or impossible?

APPENDIX D – LIFE CYCLES UNIT

LIFE CYCLES UNIT

NOTE: These are the lesson plans written for Lauren and Cecile. They are informal and make reference to our spontaneous and planned conversations.

1. Setts and Repeating Setts as Patterns

After listening to Lauren speak about the concepts she has begun to introduce to her students (living and nonliving), I decided to begin this unit with a discussion and presentation of Scottish tartans. As you know, tartans were specific to highland clans (families who shared a surname). Clan members could identify one another by the colour and colour pattern woven into the clothing or articles of clothing they wore. The problem for the children to solve is to determine how this instantaneous, visual identification of family members was possible. Obviously it's pattern recognition.

I have three authentic Scottish kilts and the following two books of Scottish tartans.
Sir Thomas Innes of Learney. (1970). *The Scottish Tartans: With Historical Sketches of the Clans and Families of Scotland, the Arms of Chiefs of Clans and Families and Clansmen's Badges, 4th Edition.* Edinburgh: Johnston and Bacon, 112 p.
Sir Thomas Innes. 1971. *The Tartans of the Clans and Families of Scotland,8th Edition.* Edinburgh: Johnston and Bacon, 300 p.

We can look at the illustrated and/ or real tartan kilts, and discuss the similarities and differences in the use of colour and in the use of line.

When this discussion has run its course, I think we should introduce the term, "pattern", if it hasn't already been mentioned. Have they ever, before today, heard this word being spoken or used it in a sentence themselves? (patterns used in sewing, plans or diagrams to be followed in making objects out of wood or other materials, an artistic or decorative design - a paisley pattern, a design of natural origin - patterns of bird formations, etc.).

With the students' input, define the term, "pattern", and write this definition where everyone can see it.

Then, you might want to ask your students if they think patterns can occur in objects or things or events other than woven tartan fabrics. As usual, it is not enough for them to answer "yes" or "no". They must either name and describe a pattern they've seen, or point to a pattern they have noticed in the classroom. In either case, they must be able to convince you and their classmates that the object or objects they are describing or pointing out make a pattern: it's that same old question, how do you know, what is your evidence for believing that.

At this point, it would be best to model the construction of an assortment of patterns.
1. Patterns based on their positions relative to one another (squat like a frog, stand like a bear; squat like a frog, stand like a bear; squat...)
2. Patterns based on colour (red, red, blue, white; red, red, blue, white; red...)
3. Patterns based on the arrangement of two dimensional shapes (triangle, triangle, circle, square, square, diamond; triangle, triangle, circle, square, square, diamond; triangle...)
4. Patterns based on three dimensional shapes and/or objects (shoe, shoe, shoe, shoe, sock, sock, shoe; shoe, sock, shoe, shoe, shoe, shoe, sock, sock; shoe...)

I hope to have enough materials to set up a living, non-living pattern. I thought I would bring in several living insects and an assortment of toys (plastic turtle, foam caterpillar, marble, shell, rock, toy car, *etc.*). Given the work you have completed this week, this could be a very interesting discussion.

The time remaining should be used for pattern making by the children. In teams of two, invite them to produce a pattern using the materials I've brought into the classroom (1 through 10 below), present it to the class or partner, and explain why they believe it meets our definition of pattern (locate the sett, how many times is it repeated).

1. K-NEX (13 white rods -3.5 cm, 10 yellow rods -8.5cm, 16 red angle connectors, 15 purple semi-circular connectors)
2. Construx (16 blue connectors, 15 gray connectors,14 black bricks-4.7cm, 14 gray bricks-1.8cm)
3. 11 almonds 18, peanuts,8 hazelnuts, and 20 acorns
4. Beads (10 pink six-petal flowers, 8 pink/silver glitter stars, 25 white cylinders, 16 turquoise/silver glitter cylinders, 23 multi-faceted turquoise spheres, 15 multi-faceted navy blue spheres)
5. Tinkertoys (12 wooden wheels, 15 white connectors, 16 yellow rods, 12 blue rods)
6. 18 red paper clips, 21 brass paper fasteners, 12 blue wall plugs, 19 flat head screws
7. Beads (12 fluted red-orange spheres, 8 smooth red orange spheres, 23 yellow cylinders, 18 orange six-petal flowers, 18 multi-faceted ochre spheres, 13 white stars)
8. 12 chop sticks, 14 yellow and white striped flexi-straws, 12 red checkers, 21 cork stoppers
9. Quercetti coloured pegs and tray (26 blue, 24 yellow, 24 green, 24 red)
10. Dried beans/peas (25 kidney beans, 41 chick peas, 50 white lima beans, 42 pinto beans, 65 black beans)

2. Seeing Patterns and Making Patterns

As we discussed on Thursday evening, this science time will be used by the children to construct patterns.

I think it would be best to begin in the friendship circle with a review of what a pattern is. Maybe we could even choreograph another pattern that has the students in three or four different positions. I have a book on snails that might be interesting to use. It not only discusses the life cycle of the snail but mentions several interesting features that the children can attempt to dramatize (egg - curl up in a ball; baby snails - on the floor, back slightly arched, arms in front and in the air - these are the two long tentacles with eyes at the end; hibernating adults - arms close to chest with back arched like a frightened cat - tentacles and bodies inside shell to escape the cold and their enemies, opening sealed with a thick plug of slime).

I will bring in the following materials for the children to use in the making of their own patterns:

1. Eight, black shoe laces (65.5cm) with red, blue, white, yellow and green opaque cylindrical beads
2. Four cans of Play-Doh (white, yellow, blue and red) and five, plastic animal cookie cutters (green fish, purple cat, purple duck, yellow bear, blue butterfly)
3. Crayola, Outdoor Adventures Mini Stampers (2 orange butterflies, 2 yellow suns, 2 maroon ladybugs, 2 blue paw tracks, 2 dark green stars, 2 purple moons, 2 yellow-green shamrocks, 2 turquoise asterisks)

4. Pentech stencils (lower and upper case numerals and letters, geometric shapes and animals) and 2 vehicle stencils
5. Coloured, sticky stamps of farm animals (multi-coloured chickens, horses, sheep, cows, pigs), and buildings (farm house, barn with silo) and tractors, and square shapes (orange, red, purple, green, blue, yellow)
6. Four, Jurassic Park dinosaur stamps, two Crayola stamp pads (blue/red and purple/green) and six self inking animal stamps (red leopard, red hummingbird, green frog, blue lizard, green toucan, purple crocodile)

In terms of assessment, I think the students should be asked to work individually but cooperatively, three or four students to a centre. The patterns they create, rotating through these six centres, can either go directly onto the pages of their science notebooks/science journals or onto paper that can be glued into these notebooks/journals.

If there is any time remaining, I have several books you might want to look through, selecting one to read to the class. The objective would be to have the children detect the pattern in the written text (story), and to look for patterns in the illustrations. The books are: Barbara Reid's, *Two by Two*; Lynley Dodd's, *Harry Mcclary from Donaldson's Dairy*; Eric Carle's, *The Grouchy Ladybug*; and Pat Hutchins', *Goodnight, Owl!*

3. Recognizing Natural and Man-made Patterns in the Environment

In a book published in 1993 by the Exploratorium, San Francisco's museum of science and art, the author Diane Ackerman writes an insightful foreword that I thought might interest you, given our present focus on pattern. It may, in fact, help set the scene for the experience I would like the playground exploration to be for the 1-2-3s. I won't write out everything she says, just what I believe to be the most relevant excerpts.

> *We crave pattern. We find it all around us in sand dunes and pine cones. we imagine it when we look at clouds and starry nights, we create and leave it everywhere like footprints or scat. Our buildings, our symphonies, our fabrics, our societies - all declare patterns. Even our actions. Habits, rules. rituals, daily routines, taboos, codes of honor, sports, traditions - we have many names for patterns of conduct. They reassure us that life is stable, orderly, and predictable. So do our similes or metaphors, because seemingly unrelated things may be caught in their pincers, and then the subtle patterns that unite them shine clear. This is sometimes how the mind comforts itself, and often how the mind crosses from one unknown continent of perception or meaning to another, by using the land-bridge of metaphor. In conversation, we meander like a river. Rocking with grief, a mourning woman keens like a wind-bent willow. The river sings. Unanswered letters dune on a cluttered desk. Families branch. Music curves, spirals, and flows. The spidery mind spins a fragile, sticky web between like things, gluing them together for future use.*
> *...Once is an instance. Twice may be an accident. But three times or more makes a pattern.*
> *We crave something familiar in a chaotic world. ...Without a pattern we feel helpless, and life may seem as scary as an open-backed cellar staircase with no railings to guide us. We rely on patterns, and we also cherish and admire them.*

When we began this unit, I suggested that patterns are formed when objects are placed in orderly positions relative to each other.
Can the children find objects placed in orderly positions relative to each other on the playground? We really only need to look, and not that far. But, we must look carefully. So, for example, they may notice several of the following relationships:

- the way the stone and mortar are used in the siding on the school (is it an English bond, a Flemish bond, a stretcher bond or a wall made without the bricks overlapping?)
- the way the big sections of sidewalk concrete are separated by the man-made expansion grooves (what might be the reason for this pattern?)
- the placement and position of cracks in the sidewalk (do they meet at right angles to one another, if so, they probably formed sequentially - one after the other)
- the way the posts with spaces in between (a pattern of support) hold up the rail for the parking lot fences
- the way the posts and chain are placed and separate the playground from the sidewalk and street
- the way the links are interlocked to form the chain
- the **symmetrical** pattern of several of the playground structures (what is symmetry and how can you tell whether a pattern is symmetrical or not?)
- and so on.

When you feel that your students understand and recognize man-made patterns in the world, move on to pattern recognition in the natural world.
It's probably easiest to begin with the trees on the school grounds, but if someone had located an orb spider's web, begin there.

Like the snail's shell, the pinecone Ackerman makes reference to, and the florets that make up the golden centre of a daisy or the browning seed of a sunflower, the orb spider's web is a spiral pattern. A spiral shape is created by adding elements that have a shape identical to the existing elements, but a different size - the newest and smallest are at the centre.

If you can't find a web, begin observing single trees and their leaves. Have the students start at the trunk and work their way up to the canopy. The trunk gives rise to large branches, the large branches support smaller branches, and the smaller branches support twigs. Make certain that they look carefully at the main branches off the trunk. Do these branches leave the trunk in a spiral or whirl pattern? Do they leave the trunk in an alternating pattern or directly opposite one another?

Now look at the leaves for the tree you have been investigating. You should find that one leaf vein flows into smaller veins which split into even smaller ones. The smaller veins usually rejoin one another and form a network. (You may want to compare this pattern with the branching of blood vessels in our bodies and tributaries that are fed by streams that are fed by trickles of water - in all three instances the number of "channels" increases in a geometric progression as you get closer to the edge of the leaf, closer to the capillaries in the extremities, and upstream to the river's source.)

Pick a blade of grass. Look carefully at the veins. Do they branch and rebranch like the tree's leaf? Usually the veins, except the tiniest ones, lie parallel to each other. Grasses, like corn and lilies and orchids and palms, are called monocots. Not only are their leaves parallel veined but they have similar flowers, similar root systems, similar stems and similar seeds. All of the other flowering plants are called dicots and they have netted veins.

Paleobotanists, specialists in plant fossils, use the branching patterns of leaf veins to identify leaf fossils. Many species of plants can be identified by their leaf vein pattern alone.

I'll try to bring in a honeycomb, bubbles and Indian corn so that the students can see the similarity in objects where there is packing. Nature tries to accomplish the tightest fit using the shortest path and the least energy. The result is that walls meet in groups of three, forming 120 degree angles or hexagonal shapes and three way junctions.

Finally we can look at the fronds of a fern and self-similarity (smaller and smaller versions of the same basic shape and structure).

These last two observations can be made in the classroom, we can then move easily into the patterned objects the children may have brought to school. The objective here would be to have them point out the "sett", to use the Scottish tartan terminology, and to show how it is repeated. In this way they provide the evidence for their belief that the object they are discussing has a pattern. If there is time, you might want to have them draw and describe their pattern (prose or symbols). At the very least, I think you would want them to write about their experience, as a detective, looking for patterns on the school grounds and in the world.

4. Cycles as Repeating Patterns

To augment the idea of cycles as repeating patterns and to help the children to begin to see more patterns and cycles in nature, I have collected the following resources (you may find others in the school's library or your own private collections of books): Gilles Tibo's *Simon in the Moonlight;* Allan Fowler's, *So That's How The Moon Changes Shape;* Gelda Muller's, *Circle of Seasons;* Bruce McMillan's, *Time To..;* Jean Marzollo's, *Sun Song;* Franklyn Branley's, *The Moon Seems to Change;* Franklyn Branley's, *What Makes Day and Night; and* Stoddart's, *Ultimate Visual Dictionary*. They can be read during science and any other time that you find a lull in your teaching day.

Definition: A cycle is a repeating pattern. Events in a cycle happen in order. Then they start again and happen in the same order.

We might want to begin by reviewing the snail pattern we had the children act out last week - egg, youth, adult. If this pattern is repeated in a circle, and we review with them that the egg is laid in the soil by the adult, that the snail hatches out of the egg and begins eating and growing, and that it reaches its adult size in two years and can then mate and lay its own eggs, they should recognize (perhaps with some guidance) that this is a cycle. That is, it meets all of the criteria set out in the definition: events that happen in order, thus, creating a pattern, and a pattern that repeats, or starts again and again, but always in the same order: egg, youth, adult; egg, youth, adult; ...

At this point, I think it would be interesting to read one of three books on natural cycles, or you may have a book on cycles that I'm not familiar with that could accomplish this objective just as well. The first selection is *What Makes Day and Night* by Franklin Branley. The second is *The Moon Seems to Change* by the same author. The third selection is Gilles Tibo's, *Simon in the Moonlight*. As you may have guessed, the first explains why we live on a planet with cycles of light and darkness. The second and third are about the phases of the moon, which run through a 29.5 day cycle.

Then we can either open up the discussion and invite the children to state the cycles they are familiar with and to tell us why they believe their contribution is a cycle (or meets the criteria stipulated by the definition), or we can provide another example, this time from the human body. There are two possibilities if you choose the latter: heart beat/pulse, or, breathing. In the first instance, they must find their pulse, which may be difficult to do. In the second they merely breathe. But for both body cycles, you should have them do some prediction before they actually count the beats or in-and-out breaths in a minute. We can then discuss the cycles they counted and the accuracy of their prediction. And, if there's time we could do some activities to see how these cycles can be changed through exercise (skipping walking, jumping-jacks) and rest.

Now, on to the recognition of cycles. I am not certain what the children will contribute to our discussions on cycles, but there are several cycles we could help them think about. These are their daily cycle of activity, the school day cycle, and cycles of time (day/night, weeks, months, and seasons, as well as the 12 hour cycle on an analog clock). There are also the cycles that they may have experienced bicycling (pedals turning around and around, links of a closed chain moved around by sprockets and gears that are turned by rotating the wheel and axle), at amusement parks (roller coaster, Ferris wheel, merry-go-round, go-carts), on playgrounds (swings), or driving around with their parents (traffic signals).

Making a cycle headband: We discussed this thoroughly on Wednesday, so I don't believe I need to say very much. We decided that one sett repeated three times would be sufficient. They could do leaf rubbings, using leaf shape and crayon colour to establish their pattern, but it may be easier just to use coloured markers.

5. Cycles: Focus on the Four Seasons

Review.
Begin by reviewing the definition of a cycle: *A cycle is a repeating pattern. Events in a cycle happen in order, then they start again and happen in the same order. These events will start again and happen in the same order forever and ever.*

Since the students have had a week to think about cycles, I think it's important to invite the children to state the cycles they are familiar with and to tell us why they believe their contribution is a cycle (or meets the criteria stipulated by the definition).

Heartbeat/Breathing Activities.
If you haven't had the opportunity to study heart beat/pulse or breathing, and neither of these cycles have been suggested by the children, you might want to take the time and introduce one or both of these body cycles. As I suggested in the previous set of notes, you might want to have the children predict the number of breaths (one inhale-one exhale) they require in one minute (or half minute - you can multiply by 2) both resting and following exercise.

Gredda Muller's *Circle of Seasons.*
Once the discussion and body cycle activities are complete, review the cycle of the seasons. Or, if you haven't had the opportunity to read Gredda Muller's *Circle of Seasons*, do so and discuss the changes that we experience in spring, summer, autumn and winter. These four seasons make a

sett, and this sett is repeated each year, so we have a pattern, and this pattern will start again and happen in the same order year after year, forever and ever, so we have a cycle.

Dramatization.
You might even want to have the children dramatize this cycle of the seasons. What would a plant, a perennial perhaps, look like in the spring when the snow has melted and the ground is beginning to be warmed by the sun? How would it look in summer? In autumn? In winter? Do they have any ideas about the way in which we could make this sett. The spring plant could be pushing through the soil toward the sunlight with its first, delicate leaves. The plant in summer could be tall and erect with beautiful flowers and all of the foliage it is going to produce. The autumn plant may turn a brilliant yellow or red or orange, but, after several frosts, the foliage and stem will begin to wilt. The plant in winter is the living root or bulb or tuber or rhizome under the ground and under the blanket of snow.

When the sett has been determined, they should arrange themselves in groups of four, so that the sett becomes a pattern that becomes a cycle.

Betsy Maestro's *Why Do Leaves Change Color?*
This would be an opportune time to read the book *Why Do Leaves Change Color?* by Betsy Maestro and the illustrator Loretta Krupinski. Can the children explain this phenomenon which happens every autumn? Let them tell you what they believe may be the cause. Then read Maestro's explanation. What did she say caused the leaves to change from green to yellow or red or orange or brown? Why may the leaves on our trees not be as brilliant this year as last year?

Leaf Rubbings to Portray the Cycle of the Seasons.
As Cecile previously mentioned, this is a wonderful activity and it fits in very well with the first term science curriculum. Before the children begin their leaf rubbings, however, discuss with them the colours of the leaves in the spring and summer, before they turned a brilliant yellow or orange or red. Is a spring leaf as dark a green as it will become in the early summer? What happens to the leaves when they fall to the ground. Do they remain a brilliant yellow or orange or red or is there a lot of brown when you get around to raking them up near the end of October or after the snow has melted in the spring? They should associate a pale, yellow green with spring. A deep, dark green with summer. Yellows, reds, and oranges with autumn. And a wide assortment of browns with winter.

These are the colours of wax crayons we will have out for them to use. They should do four rubbings of one leaf or four rubbings of four different leaves. The one associated with spring should be a pale green, and it can be placed near the top of the paper. The rubbing associated with summer should be a dark green, and it can be placed on the right hand side of the paper. The autumn rubbing should be red or orange or yellow, and it can be near the bottom of the paper. The leaf rubbing for winter should be brown, and it can be placed on the left hand side of the paper.

It is probably easiest if they do the four rubbings first and then label the seasons and draw in arrows showing the order that these events will occur and occur again (forever and ever).

In the next lesson, we will be discussing the meaning of a life cycle and arriving at the sett that makes up the life cycle of man, *Homo sapiens*. There will be two stories and the children will be asked to think about themselves as babies: their appearance and their abilities. They will then draw themselves as infants, leaving spaces for weight and height measurements. If time permits, they will write out a list of the things they could do at this very young age. I'll give you a much more thorough write-up on Monday, but my intent is to have them begin to think about the physical changes they have made in their very short lives and whether they were dependent or independent as infants.

6. Cycles: Focus on the Life Cycle of Human Beings

Bryan Mellonie and Robert Ingpen's *Lifetimes.*
I would like this session to begin with the book written by Bryan Mellonie and Robert Ingpen titled *Lifetimes: The Beautiful Way to Explain Death to Children*. I don't see *Lifetimes* as a book about death. It is really a book about life cycles: birth, living, and death. Here is the text:

There is a beginning and an ending for everything that is alive.
In between is living.

All around us everywhere, beginnings and endings are going on all the time.

With living in between.

This is true for all living things.
For plants.
For people.
For birds.
For fish.
For trees.
For animals.
Even for the tiniest insect.

Nothing that is alive goes on living forever.
How long it lives depends upon what it is and what happens while it is living.

Sometimes living things become ill or they get hurt.
Mostly, of course, they get better again but there are times when they are so badly hurt or they are so ill that they die because they can no longer stay alive.

This can happen when they are young, or old, or anywhere in between.

It may be sad, but it is the way of all things, and it is true for everything that is alive.
For plants.
For people.
For birds.
For fish.
For trees.
For animals.
Even for the tiniest insect.

There are lots of living things in our world.
Each one has its own special lifetime.

Trees that are tall and strong grow slowly, standing in the sunshine and in the rain.
Some of them live for a very long time indeed, as long as a hundred years or more.
That is their lifetime.

Rabbits and mice grow up in only a few weeks.
Then they go on to live for a year or two, crunching up carrots and nibbling at cheese until they grow old and very tired and it is their time to die.
That is how it happens to be for rabbits and mice.
It is the way they live, and it is their lifetime.

Flowers and vegetables planted as seeds at the beginning of Spring when the earth is warm, grow quickly to live through the heat of summer.
The days pass and they become old during autumn when it is cooler.
Then, when Winter comes and it is cold, they die.
It is the way they live. That is their lifetime.

Butterflies live as butterflies for only a few weeks. Once they have dried their wings, they flutter and flit from leaf to flower. At first they are bright and quick, but as time passes they begin to slow down until finally they can go no further. They rest for a while, and then they die.
That is the way butterflies live, and that is their lifetime.

Birds grow up quite quickly, too.
It is often no more than a few months from the time they hatch until they are strong enough to fly and feed themselves.
How long they live after that seem to depend upon their size. Mostly, the bigger they are, the longer they will live.
That is the way birds live:
some for as long as fifty years,
others no more than two or three.
But, however long, it is their lifetime
for each one.

Fish swimming in lakes and rivers
or in the sea, can be so tiny it is hard to tell
that they are there at all, or so big that the
only way to describe them is enormous.
Again, as far as we know, it seems that
the smaller they are, the shorter will be
their lifetime, but that is how it is for fish.
Their lives can be as little as a day or so,
or as long as eighty or ninety years.
It is the way they live,
and those are their lifetimes.

And people?

Well, like everything else that is alive,
people have lifetimes, too.
They live for about sixty or seventy years,
sometimes even longer, doing all the things
that people do like growing up
and being grown up.

It can happen, though, just as it does with

all other living things, that people
become ill or they get hurt.
Mostly, of course, they get better again
but there are times when they are so badly
hurt or they are so ill that they die
because they can no longer stay alive.
It may be sad, but that is how it is
for people. It is the way they live
and it is their lifetime.

So, no matter how long they are,
or how short, lifetimes are really all the same.
They have beginnings, and endings,
and there is living in between.

That is how things are.
For plants.
For people.
For birds.
For fish.
For animals.
For the tiniest insects.

EVERYWHERE!

<u>Discussion of Life Cycle and the Components That Must Be Included in the Life Cycle of Man</u> (human beings).

When we think about one snail's lifetime, or one bird's lifetime, or one insect's lifetime, we have birth and death with living in between. Is this a cycle? Is this a pattern?

We can think of one lifetime of one kind of animal as a sett. Except for Lonesome George, a saddle-back tortoise from Pinta Island in the Galapagos Islands who is the only saddle-back tortoise left in the world, there are many of each kind of plant and animal - they mate and have babies, and these babies grow and eventually become adults and mate and have babies. So the sett, birth-living-death, becomes a pattern when we think of families or whole groups of similar animals and plants. And since this pattern begins again and happens in the same order, forever and ever, we can think of patterns of birth-living-death as cycles. Scientists like to call these cycles of animals and plants, life cycles. So, we'll call them life cycles too.

Now, you all remember the life cycle of the snail (egg-hatchling-youth-adult). Do you think that we could look at our own lives as being part of a cycle? Is there any reason for believing that you and your parents and your grandparents and your brothers and sisters are at one point in the life cycle of human beings? What do you think? What might some of the stages that make up the sett of our life cycle be? Think of the snail and think of your own life and the people around you. What must we include in our sett, so that anyone looking at it will recognize that it's the sett for a boy or a girl or a man or a woman, not the sett for a snail, or a grasshopper, or a Canada Goose, or an oak tree?

This should be an interesting discussion. As a consequence of the book, I'm certain that they will include birth and death, but there might be a lot more that they want to include between these to events (toddler, pre-school, nursery school, Kindergarten, elementary school - early years, middle

years, senior years, high school, college/university, work, teenager, young adult, parent, grandparent, and the like).
Their suggestions could be written down and the order (sequence) could be discussed. We need to make the point, however, that everything we include between birth and death is living, and these components will not necessarily be the same for every human being.

Harriet Ziefert's Bigger Than a Baby.
This is a wonderful book that talks about babies and the things that they can do, and then discusses young children and the changes they have made in their short lives. These changes include changes in size and cognitive abilities, as well as psychological or socio-cultural changes. There should be lots of discussion, and the text will definitely help them think about the changes they have undergone.

Baby Pictures (Drawings).
The session's activity will be centered upon the children as babies, the first step in our life cycle. They must try to visualize themselves as newborns, because we want them to draw a picture of themselves as they were before they had their first birthday. So you might want them to think about the following questions: "Did you have a head, two eyes, a nose, a mouth, two ears, hair, a neck, an upper torso, two arms, fingers and thumbs, an abdomen, two legs, two feet, ten toes? Do you still have all of these same features and body parts now? Well what has changed? What was different between your physical appearance then and your physical appearance today? How could you make a drawing of yourself as a baby look like a drawing of a baby and not a drawing of a girl or boy of 3 or 4 or 5 or 6 or 7 or 8 years of age?

Make certain that they leave room at the bottom of the page for their height and weight as newborns.

If there is time, the children should begin to write the list of things they could do as a baby. It might not be very long, but that's all right. When we begin talking about animals that hatch out of eggs, especially the insects and amphibians and reptiles, they will begin to realize how much more independent these animals are as babies than the babies born to humans and other mammals.

There are two additional books I will bring in. Both deal with the growing and changes children experience as they leave babyhood behind. One is *I'm Growing* by Aliki. The other is Margaret Miller's *Now I'm Big*. If you have time, you might want to read one or both of these books to your students before we begin next week's science activities. The focus will shift from babyhood to each student's present day appearance (height and weight) and the things they can do today as 6, 7, and 8 year olds that they couldn't do as babies. The second hour session will begin to look at animals, like us, that merely grow and change proportion as they age. That is, their post-embryonic development isn't very radical, so the newborns of these species look very similar to their adult parents.

7. Life Cycles (Growing: From Newborn to Early Years Student)

I have spent the last several days trying to track down a series of video recordings called *Babies at Play*. According to the Winnipeg Public Library's on-line catalogue, there are three titles in this series, namely *Babies at Play in Their Favorite Places*, *Babies at Play Under a Blue, Blue Sky*, and *Babies at Play on a Fun, Rainy Day*. I have been to three branches in search of these titles. In each case, the librarians on duty have ended up putting traces on their copies. My plan is to pick one up at the St. James branch on Monday morning.

I thought we could begin the lesson by viewing the video recording. The children should then be given the opportunity to discuss the differences between the babies and toddlers at play and themselves. Physically they are quite similar, except for height and proportion. This is the concept they have to grasp. Human babies look very much like their parents. They have the same number of appendages and the same physical features.

I have two scientific illustrations (references immediately below) that show the changes in body proportions during human prenatal and postnatal growth. The children should have the opportunity to view these and discuss the changes that they notice.

Cecie Starr and Ralph Taggart. 1989. *Biology: The Unity and Diversity of Life, Fifth Edition*. Belmont, CA: Wadsworth Publishing Company, p. 498. Figure 34.9 Diagram of changes in the proportions of the human body during prenatal and postnatal growth. (female figure used in illustration)

William T. Keeton. 1972. *Biological Science, Second Edition.* New York: W.W. Norton & Company, Inc., p. 554, Figure 16.19 Changes in body proportions during human fetal and postnatal growth. The head grows proportionately much more slowly than the limbs. [Modified from Morris' Human Anatomy, ed. by C.M. Jackson, Blakiston, 1925.]

We should then ask the students to draw a picture of themselves just as they look at this moment. Anyone looking at their picture should be able to recognize them by the clothing they have on as well as the colour of their hair, the colour of their eyes, and so on. So, if they are wearing green corduroy slacks and a blue and green striped shirt with yellow socks and a pair of black leather shoes these items of clothing should appear on their body in their drawing. Remind them to leave room at the bottom for height and weight measurements (I'll bring a measuring tape and scale for you to use.)

If there is time remaining we might want to read one of three books that deal with changes to children (and in one case their father as well) that aren't possible. In *Imogene's Antlers*, a young girl wakes up one morning to find that she has antlers. Oli, a young boy in the book *Big Boy*, is tired of being little. He dreams that a magical bird grants him his wish "to be big. Big as a mountain and strong as the wind!" In the end he comes to the realization that there are advantages to being young. In *Piggybook*, a father and his two sons who live like pigs become pigs. The latter is certainly a case of metamorphosis, but metamorphosis as you know is not a developmental change that humans undergo. We grow in size and do not undergo drastic remodeling into the adult form. A discussion about what is possible and what is an impossibility when we consider the changes that happen to humans as they age could conclude the lesson.

8. Animals (Birds, Reptiles, Fish, Mammals) That Grow in Size With Age

<u>Melvin Berger. *Look Out For Turtles*.</u>
I would like you to begin this session of science with Melvin Berger's book, *Look Out For Turtles*. It is as much a book about conservation and survival as it is about turtle anatomy, diet, behaviour, and niche. And, it is nicely illustrated. For our purposes, it also addresses mating, egg laying, and hatching.

I have two models that you can show the children after reading the book - one is an adult turtle and the other is a turtle emerging from its egg. The two concepts you want to emphasize are the physical and structural similarities between the "hatchling" and the adult and the fact that, like the snail, the eggs are not protected. They are laid and left. The newborn turtles, as a consequence, are not cared for and raised by their parent or parents, but immediately know all they need to know to live by themselves. They are independent. What exactly does this mean? Well, if they are a turtle (not a tortoise) they do not need to be taught how to walk from the nest to the water. They do not need to be shown the direction in which to go to find water. They do not need to be taught how to use their flippers to swim in the water. They do not have to be fed, but know what to eat and how to find and catch it. They know that they are safe from harm if they pull their head, tail and four legs into their shell. No one teaches them these things. In fact, they are born knowing how to do most of the things the adult turtle can also do. This is not very much like us. As newborns we depended on our parents and care givers for just about everything (food, warmth, shelter, hygiene, stimulation, locomotion, love and affection, etc.)

<u>Activity #1 - Matching Game</u>
I have made a matching game using scanned photographic images of young and adult animals. Included in this game are two <u>birds</u> (cygnet and adult swan, chick and adult budgerigar), a <u>fish</u> (a week old fry and adult common goldfish), two <u>reptiles</u> (snake and gecko), and nine <u>mammals</u> (puppy and adult guinea pig, calf and adult elephant, cubs and adult polar bear, foal and adult zebra, cub and adult tiger, calf and adult giraffe, joey and adult wallaby, calf and adult camel, and a newborn and adult hedgehog). I had the pages that I laid out and printed, photocopied in colour. So, four groups of children will have a set of fourteen young and mature animals to sort. The point of the game is for them to recognize which baby belongs with which parent or which parent may have given birth to which baby. They should be given sufficient time to make these decisions. I don't think they will have much trouble because most of the animals look like miniature (or scaled down) versions of their parent. Regardless, this is what they must come to realize. All of these animals give birth to babies that resemble their parents in structure. They may have little or no hair, few if any feathers, but they share a common physical appearance.

I think it's important that you ask each group or specific children to justify (provide evidence for the correctness of) their matches. It isn't enough to simply do the activity. The children must be able to articulate the features they see in both the picture of the young animal and the picture of the adult animal that led them to their decision to pair them. Is it possible to make this pairing looking at eyes alone? Could you match the pictures only looking at the animal's feet? Hair? Ears? Snout? What else does one need to pay careful attention to if all the pairings are going to be the correct ones? It's not correct for them to say that we paired the fry with the goldfish because they were the only two fish. Or that we paired the coloured chicks with the coloured budgies. Would this have worked if we had nine pairs of fish and nine pairs of birds? They have to be more astute.

<u>Activity #2 - Partner Reading (*See How They Grow* books)</u>
These are wonderful books put out by Scholastic and Dorling Kindersley. I have managed to find eleven different titles in this series. These are *Calf*, *Lamb*, *Foal*, *Mouse*, *Rabbit*, *Fox*, *Puppy*, *Pig*, *Chick*, *Owl* and *Duck*.
I think it would be interesting to have pairs of children read these books and then tell their classmates about the animal they have just read about (focusing on the similarities and dissimilarities between the young and the adult and the changes that occur as the animal ages). Do they think their animal is dependent at birth, or independent at birth? Is it like the snail and the turtle or does it more closely resemble a human baby? If it is dependent, what kinds of things will it have to learn from its parent or parents to become independent?

Science Reading and Videotapes *(if there's a lull during the week that can only be filled with a story or film)*
I am also giving you several books. These are *Baby Animals*, *Snakes Are Hunters*, *A Fish Hatches*, *A Duckling is Born*, and *Baby Birds and How They Grow*. There are models (snake, fish, penguin) to go with each story.

There are also two video recordings from the Sony Wonder "See How They Grow" series that I have included. They are wonderful, and were made for children of this age. *Farm Animals* features chicken, pigs, calves and lambs. *Wild Animals* features rabbits, foxes, snakes, and pheasants. I also have a copy of *Forest Animals*, but I don't think there will be time for it until next week.

What I hope the children will learn from these readings and films is that four groups of animals - the reptiles, the mammals, the fish and the birds have offspring that resemble adults as young. They are simply smaller and grow with age.

9. Animals That Change Form and Structure as They Age (Newborns Do Not Resemble Adults) - Focus on Amphibians

After reviewing the previous day's work on reptiles, birds, fish, and mammals (newborns resemble their adult parents structurally and grow with age to the size of the adult), I would like you to begin the lesson with a book by Millicent E. Selsam and Joyce Hunt, *A First Look At Frogs, Toads and Salamanders*. The text provides a good introduction to amphibians - what they are and what they are not. It then continues with an explanation of the distinction between frogs and toads and salamanders. It also asks the reader to use his or her knowledge of shapes and patterns to identify specific amphibians.

There will probably be a lot of discussion about this book. The concept you want to make certain the children become familiar with, however, is the fact that the newborn amphibian tadpole does not, in any respect, resemble its adult parent. It is much more fish-like than frog-like or toad-like. It has an elongated body with a large head at one end and a tapered tail at the other. There are two small eyes, a small mouth and external gills. This is a very different situation compared to the other animals we have looked at (the turtle, the snake, the rainbow trout, the snail, the cow, the pig, the rabbit, the horse, *etc.*) which at birth look much like the adults except for size - they will grow with age.

I have a set of six plastic models which show this gradual transformation from tadpole to adult frog. You will want to show each model to your students and have them discuss what they see and the structural changes that occur from one stage to the next in the frog's life cycle.

When every child has had the opportunity to hold and observe each of the models, you should display them in a prominent place and read *Frog* by Michael Chinery. This is an excellent book, and I think you and your students will get a lot out of it if they have the patience to sit through another reading. It is well illustrated and packed with interesting information.

The *See How They Grow: Pond Animals* video recording is an excellent way to summarize the ideas they have been exposed to in Selsam's/Hunt's and Chinery's books. You may want to skip over the first segment on ducks and show the second segment on frogs (the forth segment is on dragonflies, which we'll be studying in an upcoming session).

I am also leaving three other books on frogs with you. One is from the Scholastic *See How They Grow* series, titled *Frog*. The other two are Kate Petty's *Frogs and Toads* and Gail Gibbons' *Frogs*. You may want to have them out for silent or partner reading, or you may choose to read them, at an opportune time, to the students in your class.

10. Review Animals That At Birth Resemble Their Parents and Introduce The Insects

Have the children sit in a circle on the floor. What they are going to do is name an animal that gives birth to a baby that resembles (looks like) its adult parent. Each student should be asked to give the name of one animal that no one else has yet mentioned. Review the pervious day's work. Remind them that we have looked at five groups of animals, the amphibians, reptiles, birds, fish and mammals. Only the amphibians, of these five groups of animals, produced babies that didn't at all resemble their parents (a tadpole and a frog). The reptiles (snakes, turtles, and alligators/crocodiles), mammals (cattle, pigs, dogs, cats, monkeys, horses, sheep. foxes, giraffes, elephants, etc.), fish (goldfish, rainbow trout), and birds (chickens, ducks, penguins) all produce young that resemble the adult of the species. That is, the newborns and the adults have the same physical structure, one is simply smaller, but it will grow with age.

I'm not certain how much time this activity will consume. It will depend upon how well the children have grasped this particular concept. I can't imagine that it will take the entire 60 minutes, so I am planning on there being twenty or so minutes to introduce that component of the animal kingdom known as the insects.

For this particular activity you may want to refer to Selsam's and Hunts's book, *A First Look at Insects*. They nicely make the point that the characteristics that distinguish insects from all other animals are their possession of an exoskeleton, three pairs of jointed legs, a body divided into three main regions (head, thorax, and abdomen) and they carry their mouth parts externally on their head.

I have several models of insects you may want the children to examine (large yellow-ochre grasshopper, small green grasshopper, cricket, bumblebee, three ladybug beetles, dragonfly, housefly, carrion beetle, soldier beetle, longhorn beetle, ant, wasp, cockroach, etc. They should look for 3 pairs of legs, three body parts, antennae, a set of large, compound eyes, and external mouth parts. Most of the insects they will be looking at are winged. There are two orders of insects, the bristletails and the silverfish, however, that are wingless. These are also the two insect orders that do not undergo metamorphosis. The young resemble the adults in all respects except size and sexual maturity.

I have set up a terrarium with ladybug beetles and crickets. Make certain that the children have many opportunities to view the adult beetles and cricket nymphs. There is also an assortment of books on insects that you may want to read to your students or have available for partner reading. These include the following: *The Very Quiet Cricket*, *Backyard Hunter: The Praying Mantis*, *Amazing Insects*, *Dragonflies*, *Discovering Crickets and Grasshoppers*, and a textbook *on Animals Without Backbones*.

11. Insects with Gradual/Incomplete Life Cycles: Egg - Nymph - Adult

There are a number of insects that begin as eggs but do not hatch into larvae. When they hatch they look very similar to the adults of their species, however, they are smaller and they lack fully developed wings (in place of wings they possess wing buds). These newly hatched insects are called nymphs. Nymphs cannot fly. They feed and grow and shed their outer skin (molt) to allow for increase in size. Each time they molt, they leave their exoskeleton behind and become larger; their body form does not change except for the appearance of short wings at the time of the later molts. When the nymphs are full grown they shed their skin for the last time and become adults with fully developed wings.

These insects, then, pass through three stages of development - egg, nymph, and adult. They grow in stages, not continuously as we and other mammals, reptiles, fish and birds do. And, there is no resting stage (or inactive stage) before the change into the winged adult. Some authors call this three stage life history *simple or incomplete metamorphosis* (met uh MOR fuh sus). Entomologists have given it another term, *hemimetabolous*.

A large number of insects fall into this category (or Division Exopterygota - exopterygote is the term given to the development of wings on the outside of the body). The insects you may be most familiar with include grasshoppers and crickets, dragonflies and damselflies, cockroaches, termites, aphids, walking sticks, mantids, giant water bugs, katydids, cicadas, spittle bugs, leafhoppers, and treehoppers.

I thought we would focus on grasshoppers, crickets, praying mantids, and dragonflies. I have borrowed several books from the public library on these insects (*Dragonflies, Backyard Hunter: The Praying Mantis, Dragonflies by Oxford Scientific Films, Discovering Crickets and Grasshoppers, and The Very Quiet Cricket*) and there are the living crickets in the terrarium as well as the grasshopper, dragon fly and praying mantid models that I will make available.

You may want to read several of the books to the children in your classroom, paying particular attention to the eggs, nymphs, and adults of each insect species.

I have also checked out the *See How They Grow: Insects and Spiders* video recording and will re-new the *See How They Grow: Pond Animals*. The former has a segment on grasshoppers, the latter has a segment on dragonflies. These videos are so well done, and I think the children enjoy watching them. Plus they reinforce the concepts we're trying to help the children understand.

If there is time, you might want to contrast the life history of these insects with the amphibians (frogs, toads, and salamanders) or mammals, reptiles, birds and fish and have the children discuss the similarities and differences that have become apparent to them.

12. Insects with Four Stages in Their Life Cycles: Egg - Larva - Pupa - Adult

Evolutionary and developmental biologists would argue that those insects highest on the family tree are the ones that pass through four stages of development. Among these insects, the young that hatch from the eggs are called larvae (singular: larva). Larvae are usually in the form of a caterpillar, a grub, or a maggot. Caterpillars are elongate and soft-bodied. They creep about on three pairs of legs and are of various colours and sizes. Grubs are usually white. They are most frequently found in soil with their bodies curled up in the form of the letter "C". Like the caterpillar, grubs also have well-developed legs and chewing mouth parts. Maggots, by contrast, are spindle shaped and have no legs. They are white in colour and have inconspicuous mouth parts.

The form of a larval insect is generally governed by the kind of life it leads. Larval honeybees, wasps, hornets and ants, for example, develop in wax cells where they are well protected and fed by workers. These larvae do not need legs since they have no need to move about and find food.

It is during the larval stage that insects do most of their feeding and growing. This stage, in fact, is when insect pests are most destructive. As the larva eats, it grows and it must shed (molt) its hard exoskeleton (which fits like a suit of armor and cannot grow or stretch) to allow for increase in size. Molting is not only dangerous for insect larvae, it is also hard work. Once the new exoskeleton is free of the old exoskeleton, the larva puffs its new skin full of air. The skin then hardens and the larva returns to eating. It continues to eat until is has replaced all the air with food. As a larva, it will molt many times; the exact number of molts varies with the insect. Most insect larvae complete their growth in one summer or, often, in a few weeks. When the larval insect has completed its growth, it seeks a protected place (rolled into leaves or chambers burrowed in the soil) or constructs some sort of shelter (cocoon or chrysalis). It then sheds its skin for the last time. It is now a pupa.

The pupa is the third stage in the insect's life. As a pupa, the insect has a mummy like appearance. It does not feed and it is usually inactive. While in this stage, great changes take place in the insect's body and internal organs (there is degeneration of most of the larval organs and a rebuilding of new tissues). In the case of a butterfly or moth, habits change from feeding upon plant tissues to sucking out the nectar of flowers. The greatest transformation, however, is from a creeping caterpillar to a winged, adult insect adapted for flight.

The adult insect, the final stage in the life cycle, lives just long enough to find a mate. It mates so that more eggs can be laid, so that there will be more insects to mate and lay more eggs.

These insects, then, pass through four distinct stages of development - egg, larva, pupa, and adult. Like the exopterygotes, they grow in stages, not continuously. But unlike the exopterogotes, there is a resting stage (or inactive stage) before the change into the winged adult. Some authors call this four stage life history *complete metamorphosis*. Entomologists have given it another term, *holometabolous*.

A large number of insects fall into this category (or Division Endopterygota - endopterygote is the term given to the internal development of wings). The insects you may be most familiar with include butterflies and moths, ants, bees, wasps and hornets, mosquitoes, beetles, houseflies, fruit flies, and horseflies.

I thought we would focus on butterflies, ladybugs, and Cecile's yellow mealworms (larvae of the grain beetle, Tenebrio molitor). It would be wonderful if we could make time for mosquitoes, honeybees, fireflies, house flies, ants, and wasps. These are insects whose life cycles I believe Manitoban children should become familiar with. They are certainly all around us during the warm months of summer.

I have borrowed a number of books from the public library and will bring in several of my own. These include the following: Scholastic's, *See How They Grow: Butterfly, Amazing Butterflies and Moths*; Vivian French's, *Caterpillar, Caterpillar*; Joanne Ryder's, *Where Butterflies Grow*; Gail Gibbon's *Monarch Butterfly, Life of the Butterfly* (A Carolrhoda Nature Watch Book), *The Butterfly Cycle* (Oxford Scientific Films); Margery Facklam's. *Creepy,Crawly Caterpillars*; Selsam's and Hunt's, *A First Look at Caterpillars;* Emery Bernhard's, *Ladybug, Life of the Ladybug*; Sylvia Johnson's, *Beetles* and *Fireflies*; Judy Hawes', *Fireflies in the Night*; Bainca Lavies', *Wasps at Home*; *The Housefly* (A Carolrhoda Nature Watch Book); Charles Micucci's, *The Life and Times of the Honeybee*; Joanna Cole's, *The Magic School Bus Inside A Beehive*; *Life of the Honeybee* (A Carolrhoda Nature Watch Book); Christopher O'Toole's, *Discovering Bees and Wasps*; Dorothy Patent's, *Mosquitoes*; and Caroline Greenland's, *Ants*.

I am going to try to get several pinned insects for the children to observe. There is also *the See How They Grow: Insects and Spiders* video recording that has segments on the butterfly and the ladybug that you may want to set aside time for the children in your classroom to watch.

In addition, I have made several sets of poster board wings and purchased some knit, sweater-like fabric that is manufactured in sleeves or tubular pieces, rather than flat rectangular pieces. I thought we could use these materials in dramatizing the life cycle of the butterfly. A child could shape their body into a tight ball for the egg. The larva could be a child's body stretched out on the floor, stomach down, hands on floor near chest and elbows at waist, that moves by sliding the feet forward, humping the back, and then extending the upper torso forward until the body is again flat on the floor. This could be done while inside one of the sleeves of fabric. If you choose to use the fabric as the exoskeleton for this stage in the life cycle, select the colours that are most similar to the colours of caterpillars in nature. The fabric is very stretchy and comes in several diameters. It might be possible to have a child in the tightest sleeve first. As they eat and grow, this sleeve will be much too small. The exoskeleton must be shed. So they struggle out of it and replace it with a larger sleeve. Now there is room again to eat and grow before the next molt. The pupa state will be the child enclosed in the off white tubular material. The pupa rests for most of this stage, but begins to struggle out of the chrysalis as it emerges. This will again be the situation the child experiences in these tubular pieces of fabric. The adult adorns the wings that tie around the chest with the attached strings. There are extra pieces of poster board if children would like to make their own butterfly wings. If you can set aside time for them to do this, I suggest that they look at the butterfly field guides and books with photographic illustrations of butterflies, so that the wings they shape and design represent a the wings of a species found in nature.

13. Presentation of Insects (Living, Pinned, Preserved, and Photographed) by Members of the Department of Entomology, University of Manitoba

14. Local Insects with Four Stages in Their Life Cycles: The Life Cycle of the Honeybee

I have several books that may help you in your discussions of the honeybee, and its life cycle. These are: Angels Jalivert's, *The Fascinating World of Bees*; Christopher O'Toole's, *Discovering Bees and Wasps*; and Johanna Cole's, The Magic School Bus Inside a Beehive.

Some bees, and this includes the honey bee, are social insects. Insects that live together in colonies, whether these colonies occur in nests (ants) or hives (some wasps and some bees) or mounds (termites), are designated social insects. Social insects don't live alone like the praying mantis but live in a society populated with hundreds or thousands like themselves, sometimes hundreds of thousands, and in the case of termites, millions.

NOTE: You may want to use community in place of society because of your Cummuni-Quest Project, but to be biologically correct, society is the preferred label. In biology, communities are made up of populations of many plant, animal, fungus, protist, and monera species.

It is not simply having a large number of the same kind of insect living in one nest or hive or mound that makes a society. In societies, the insects have very specific jobs to do. Julivert, in her discussion of bee societies, puts it this way: "Bees are social insects. This means they live in a community [!] in which each bee carries out a specific function that is absolutely necessary for the survival of the colony." If you decide to use Julivert's book, this will become very clear to the children.

Normally a honey bee society is populated by three kinds of bees. These are a queen bee, who lays all of the eggs; hundreds to tens of thousands of worker bees, and four or five drones. The worker bees are females and the drones are males. The drones are larger than the worker bees, but smaller than the queen. They lack a stinger, have eyes much larger than the eyes of a worker, and can not feed themselves. A drone does no work other than to mate with the queen. When winter approaches, and the bees have to think about conserving their stored food, the workers often push the drones out of the hive. Because they cannot feed themselves they quickly starve.

The queen lays eggs in small cavities called cells. After only three days, the larva emerges, but it doesn't leave the cell. It looks nothing like the adult bee, but is worm-like in appearance, with no wings or legs. The larva is fed by a nurse bee. It eats a lot and grows rapidly so that it soon fills the entire cell. When it has reached this size, it enters the phase of the pupa. The workers seal the entrance to the cell. Little by little the pupa changes its form, developing wings, legs, antennae and compound eyes. At the end of metamorphosis, the adult bee emerges, completely formed.

The period of metamorphosis is 16 days for the queen, 21 days for the worker and 24 days for the drone (the largest honeybee). The kind of bee that emerges depends not only of the size and location of the cell but also the kind of food fed to the larva. Worker bees receive a mixture of pollen and honey, sometimes called "bee bread". The queen is fed "royal jelly", a nutritious food (very high in protein) secreted by the nurse bees.

If a worker emerges from the cell, it does not immediately leave the hive looking for nectar and pollen. There are five stages of work it must first complete. It begins as a house bee cleaning up the empty cells so that they can again be used by the queen. She will not lay an egg in a dirty cell. When the house bee is three to ten days old, it becomes a nurse bee that cares for the eggs, larvae, and pupae. The nurse bee then moves on to become a wax bee. A wax bee repairs old cells and builds new cells using a special wax secreted by wax glands covering the underside of the abdomen. When the period of this job ends, the wax bee becomes a storage bee. The storage bee takes the nectar and pollen brought back to the hive and places it into cells. The cells are eventually capped when they are full and the honey, which the nectar mixed with bee enzymes has become, is of the proper consistency. When the workers have finished their duties as storage bees, they become guard bees. As a guard bee, their job is to defend the hive from predators and intruders. The final job of foraging, collecting the pollen and nectar, is the work of the most mature bees. The guard bee becomes a forager bee, and it is the forager bees that we encounter on flowers or in their flight to and from the hive. They are the only bees we tend to see, unless we have a relative or friend who is a beekeeper and runs an apiary.

The worker bee lives about 6 to 8 weeks and forages for about three weeks. After this, her wings are too worn out and she fails to return to the hive.

The children may be interested in the queen, and how the queen for a hive is selected. It seems that the first queen to emerge as an adult goes through the cells and kills the other queen pupa which have not yet emerged. If two emerge simultaneously or within minutes of one another, they fight to the death using their straight, barbless stingers. The winner becomes the new queen and she mates with the drones, and drones from other hives, while flying through the air above the colony.

Interesting Facts (from: http://www.bees4kids.org.uk)

1. Most bees in the world are solitary bees.
2. In addition to honeybees and solitary bees, there are several kinds of bumble bees.
3. To convert nectar to honey, bees mix enzymes with nectar and remove much of the water. The water is removed by the storage bees. They fan at the entrance and drive air over the curing honey until it is the proper consistency.
4. In summer, a typical hive of honeybees might contain 1 queen, 250 drones, 20,000 female foragers, 40,000 female house bees, 5,000 to 7,000 eggs, 7,000 to 11,000 larvae being fed, and 16,000 to 24,000 pupae developing into adults in sealed cells.
5. A larva that will develop into a worker bee is fed 1300 meals a day.
6. The queen can lay up to 2000 eggs a day. This is about twice her body weight. She does this around the clock for up to five years with only five to ten minute breaks.
7. Workers develop from fertilized eggs. Drones develop from unfertilized eggs.
8. Drones die after mating with the queen.
9. To collect half a kilogram of honey (a pound) a bee might have to fly a distance equivalent to twice around the world. This is likely to involve more than 10,000 flower visits on perhaps 500 foraging trips.
10. Bees eat pollen to make royal jelly and bee bread (a mixture of pollen and honey). Both are high in protein and fed to all the larvae.
11. A colony can use 32 kilograms of pollen each year. This requires over 300,000 foraging trips, with up to one million grains of pollen collected each trip.

15. Local Insects with Four Stages in Their Life Cycles: The Life Cycle of the Ant

I thought that we should take a different approach with the life cycle of ants. Rather using only images from a trade book, I would like to begin with a story book. The trade book can be used to illustrate information not included or insufficiently elaborated in the story. The story book I've selected is Chris Van Allsburg's *Two Bad Ants*. The trade book is *Ants* by Caroline Greenland. Both should lead to interesting discussions.

You may want to begin with a review. There are several approaches that can be taken. For example, you could begin by saying that ants are social insects like honeybees. Invite the children to discuss the notion of an insect society, what this means for the honeybee, and what it might mean for the ant. Do they think that an insect that doesn't undergo complete metamorphosis would be a social insect? Why or why not. Given what they know about the life cycles of insects, would they like to suggest what the life cycle of the ant might be. The review could also begin here with a discussion of four stage metamorphosis. How does the life cycle of the butterfly differ from that of the honeybee? When the caterpillar (butterfly larva) emerges from the butterfly egg is it dependent on adult butterflies? Could the honeybee larva find food and feed itself as the caterpillar does? Can it move about? Is there anything in the honeybee's life cycle that compares to the chrysalis? If so, does the honeybee larva produce this "case" without the help of older bees? Since the ant is a social insect like the honeybee, do they think older ants might care for the eggs? What do they think emerges from the egg? Will this be dependent on older ants or able to survive without any care? Whichever approach you decide to use, you will want to make certain that the children have an understanding of the social insects and the stages through which they pass with age. Continue the discussion as you read Van Allsburg's book.

I've brought a copy of the video *Let's See How They Grow: Forest Animals* which has a segment on leaf cutting ants. If you have time, play it for the children. It would be nice if you could set aside a few minutes at the end for comparing the film's visual and auditory information with what was earlier discussed and read. (You will notice that the narrator talks about the three stages in the ant's life. What are these? What stage has been left out?)

16. Local Insects with Four Stages in Their Life Cycles : The Life Cycle of the Mosquito and Lady Beetle

The Mosquito.

Most of the insects we've studied up to this point have been terrestrial. They spend their lives on, above, or in the earth. Only the dragonfly, which begins its life as egg and nymph in water, can be considered aquatic. The mosquito differs from the dragonfly in undergoing four stage metamorphosis and spending the larva and pupa stages in the water.

The information below is from two web sites that you might want to access for their diagrams, illustrations and videos.

1. http://www.co.leon.fl.us/mosquito/video/lifecycle/lifecycl.htm

Some mosquitoes lay individual eggs on the sides of treeholes or discarded containers, or in depressions in the ground that will hold water. The eggs can lay dormant for several years. Some eggs will hatch when they are flooded by rainfall. Several flooding and drying cycles are usually required for all of the eggs to hatch that are laid by a particular female mosquito. Other mosquitoes lay eggs directly on the surface of water. The eggs are attached to one another to form a raft or the individual eggs float on the water. These eggs hatch in 24-48 hours releasing larvae that are commonly called "wrigglers" because you can often see the larvae wriggling up and down from the surface of the water. Generally, the larvae feed on microorganisms and organic material in the water, but some mosquitoes prey on the larvae of other mosquito species and are regarded to be beneficial. In about 7-10 days after eggs hatch, larvae change to the pupal or "tumbler" stage in preparation for adult life. Female mosquitoes begin to seek an animal to feed on several days after emerging from water. Male mosquitoes mate with females one to two days after the females emerge. Males do not bite, but they do feed on plant juices.

2. http://www.mosquitoes.org/Mosquitoes/LifeCycle.html

The length of life of the adult mosquito usually depends on several factors: temperature, humidity, sex of the mosquito and time of year. Most males live a very short time, about a week; and females live about a month depending on the above factors.

The feeding habits of mosquitoes are quite unique in that it is only the adult females that bite man and other animals. The male mosquitoes feed only on plant juices. Some female mosquitoes prefer to feed on only one type of animal or they can feed on a variety of animals. Female mosquitoes feed on man, domesticated animals, such as cattle, horses, goats, etc; all types of birds including chickens; all types of wild animals including deer, rabbits; and they also feed on snakes, lizards, frogs, and toads.

I have also brought in the book *Mosquitoes* written by Dorothy Hinshaw Patent. It has some illustrations (perhaps not the clearest for all purposes) and good information on the stages in the mosquitoes life cycle.

You may want to talk about the high pitched whine/buzz that the mosquito makes and where this sound originates. Ask the children if these sounds are made through its mouth as we make sounds. There is an interesting book, a West Aftican tale, that would nicely compliment this discussion if you feel you can take the time to read it. The author is Vera Aardema and the title is *Why Mosquitoes Buzz in People's Ears*. I have a copy if there isn't one in the school's collection. I'm certain it would lead to interesting questions and discussion.

<u>The Lady Beetle (Ladybug)</u>

The children who participated in the Canadian Nature Federation's Lady Beetle Survey will be very familiar with these insects, but probably only the adult stage. You may want to begin by inviting all children to talk about their experiences with these little colourful beetles, or you could begin with the discussion of the adult beetle and the stages it passes through before reaching this final form. If you choose to begin this way, I would suggest that you think about your questions so that the children are the ones who make the connections between a four stage terrestrial insect and the lady beetle.

My preference is to begin with the rhyme, "Ladybug, ladybug fly away home...", and the history behind it. I think the understanding we hope the children will develop about the ladybug's life cycle will come through the discussion during and after the reading of Gladys Conklin's book, *Lucky Ladybugs*.

If you don't remember the ladybug rhyme, here is the complete text:

Ladybug, ladybug fly away home
Your house is on fire and your children are flown
All but one, and her name is Anne
And she hid under the pudding pan.

It had been recited in England hundreds of years ago when farmers were burning the straw from their crops and cuttings from their vineyards. In starting these fires, they hoped to kill aphids, but they wanted the lady beetles to fly away to safety. They didn't want any harm to come to them because aphids are a large part of a lady beetle's diet and aphids suck the sap out of plants and reduce the farmer's yields. In the mid-1700s, the song appeared in Mother Goose.

The Conklin book is a wonderful story about the activities of adult lady beetles. What it doesn't say about the egg, larva, and pupa stages can be found in the illustrations and writing of Heiderose and Andreas Fischer-Nagle's book, *Life of the Ladybug*. Unfortunately, Conklin's book is out of print (1968, New York: Holiday House, Incorporated), so I'm including the text here, in case you would want to make use of it in future years.

A ladybug is lucky.
She does not need to fly
away home. She has a new
home everyday.

Her house can't burn.
It is a blade of grass,
a leaf on a rose bush,
or in the center of a daisy.

A ladybug wouldn't know
her children if she saw them.
She lays her tiny yellow eggs on
a leaf and flies away and leaves them.

In about five days the eggs
hatch into baby ladybugs.
A baby ladybug is called a larva.
It doesn't look anything like
its parents. But it eats the
same kind of food.

These little larva are
lizard-like creatures that run
rapidly on six long black legs.
Their long pointed bodies are often
marked with orange or blue.
The larvae have greedy appetites
and eat tiny insects called aphids.
In about three weeks they are ready
to turn into pupas.

The pupa rests for a week.
It can't walk around but
will jerk up and down when
bothered. The sun warms it.
The wind blows on it.
Inside the pupal shell
a wonderful thing is happening.
The little larva is changing
into an adult ladybug.

One day the pupal shell splits open. Out crawls a pale ladybug.
It sits quietly, waiting for its body to dry and harden.
Slowly its color deepens
And black spots appear on its back.
Now it is ready to fly.

Most ladybugs wear shiny polka-dot dresses
of red with black dots.
Some have two dots. Others have five,
seven, and even fifteen dots. Some are
plain red with no dots.

A ladybug is really a beetle
and its real name
is ladybird beetle.

When the sun is shining,
ladybugs busily crawl
around on leaves, or rosebuds,

or blades of grass.
They are hunting for aphids.
They eat dozens of them everyday.

When it rains, ladybugs crawl
under a leaf and keep dry.
When the rain stops, they open
their hard wing covers, unfold
their delicate flying wings,
and depart to new places.

A ladybug keeps itself very clean.
When it finishes eating, it
washes its face with its front legs.
Then it holds each front leg up to
its mouth and carefully nibbles it
until it is completely clean.
The other legs are briskly
rubbed together to clean them.

When the days become cold,
ladybugs hunt for a warm
place to spend the winter.
Sometimes they creep into cracks
in houses or barns, or sleep snug
and warm under haystacks.

In some places, all the ladybugs
for miles around gather into a cloud -
thousands and thousands of them -
and fly to the mountains.

They crawl under rocks, or loose
bark on trees, or creep under
heaps of dry leaves.

In some of the southwestern states
tons of ladybugs are scooped into sacks.
They are kept in cold storage until
the following spring.

Then the farmers buy them by the quart
or the gallon. The ladybugs are set free in the
fields and spend their days eating aphids.

In the mountains.
there is a rush of activity as the
ladybugs come out of their deep sleep.
The tree trunks and rocks turn bright red
as the mass of thousands of ladybugs starts to move.

Soon the air is filled with a
silent swarm of tiny scarlet beetles.
They circle higher and higher,
up and up until they meet
the prevailing winds.
Then they ride the airways back to the fields
and gardens in the valley below.

Ladybugs are lucky!
Birds do not like the taste of them.
People like to have them in their gardens.
There is always plenty of food for them to eat.
Ladybugs are found all over the world.
They are welcomed in every country.

Many people consider it a sign of
good luck when a ladybug lands on them.
There is a story that long ago some
grain fields were being destroyed by aphids.
In answer to prayers, a swarm of little
red beetles appeared and ate the aphids.
Since that time, ladybugs have been
known as a special friend of man.

When you find a ladybug,
Hold it gently on your finger
Then let it fly away.
It may be lucky for you.

This should lead nicely into the final projects for art: the ceramic lady beetle paperweight and the lady beetle life cycle Christmas card. I made a mock-up of the card based on May Ling's *Wild Animal Go-Around*. It should be perfect for the children to draw the egg, larva, pupa and adult stages upon. We'll just have to watch carefully so that the right stage is illustrated in the correct quarter of the disk, otherwise when the disk is spun you may have the adult following the egg. This, I know, would frustrate several of the children who want the correct order for the sett and life cycle.

Appendix E - List of Slides

Presented by T. McKay and C. Wytrykush,

Entomology Department, University of Manitoba

PRESENTATION OF INSECTS (LIVING, PINNED, PRESERVED, AND PHOTOGRAPHED) BY TANJA MCKAY AND CARLA WYTRYKUSH OF THE DEPARTMENT OF ENTOMOLOGY, UNIVERSITY OF MANITOBA

SLIDE LIST

(Tanja worked the remote and stood by the projector at the back of the room while Carla stood to the left and right of the screen pointing out the things Tanja spoke about and contributing important pieces of information herself.)

1. Ant - discuss the characteristics of insects that make them distinct from all other animals (external skeleton, three body parts - head, thorax, and abdomen, three pairs of legs that are part of the thorax, and antennae that are part of the head).
2. Wasp - even though all insects have three distinct body parts, not all insects have heads and thoraxes and abdomens that look the same. The abdomen of the wasp is attached to the thorax by a very narrow isthmus-looking structure.
3. Robber fly - information focused on the eye of insects which is a compound eye. A compound eye isn't at all like our eyes, it would be like having hundreds or thousands of eyes in one.
4. Eggs - the development of an insect begins with the egg stage. This slide showed a number of eggs on a leaf.
5. June Beetle Larva - the second stage in the development of an insect is the larva.
6. Cocoon - the third stage in the life cycle of the insect is the pupa stage. This is the resting stage. The insect doesn't eat during this stage. The cocoon is the shell of the pupa. It must bite its way out of it.
7. White Butterfly - This is the final stage in the life cycle. An adult emerged from the cocoon or pupa case. At this point Willie spoke up. He said, "My Mom hates those ones. Those ones that eat broccolies, broccoli plants. They turn into white butterflies."
8. Molting Cicada - as insect larva grow they become too big for their external skeleton (exoskeleton) and must shed it, or molt. As insects molt, they don't just replace the exoskeleton that covers their thorax or abdomen. The exoskeleton that covers their entire body, head, eyes, legs, etc. is replaced.
9. Molting Dragonfly Nymph - another picture of an insect molting. This is an aquatic insect. Willie speaks up saying, "My class did how dragonfly grows."
10. Ants in Amber - mention Jurassic Park and the fact that tree sap becomes amber and that the insects caught in the sap will also be preserved.
11. Beetle Markings in Wood - the beetle (as larva and adult) lives in the wood creating tunnels as it moves around.
12. Man Standing Next to a Termite Mound - the mound is much taller that the adult male standing next to it. This is the home of termites. It is even temperature controlled. So they have air conditioning like we do in our homes.
13. Forest Tent Caterpillar - shows the silken threads that surround forest tent larvae and give it this insect its name.
14. Trails of the Leaf Minor - this insect lives in the tissue between the upper and lower epidermis of a leaf. We can see the tunnels that it has made as it eats its way through the leaf tissue. Some insects cause damage to leaves and crops.
15. Beetle and Larvae Eating Grain - the insect in two stages are all over the seeds.
16. Lousefly - an insect like the mosquito that is shown biting human skin.
17. Lady Beetle Larva and Fly Larva Eating Aphids - insects even eat other insects.
18. Insect Eating Caterpillar - straw-like mouth parts used to suck up the fluids inside the caterpillar (larva).

19. Giant Water Bug - front pair of legs are adapted to catch and hold prey.
20. Beetle - shows how jaws, not legs, have been modified to catch prey.
21. Bird Feeding Insects to Its Babies - insects are an important source of food for many kinds of birds.
22. Alder Fly Larva - an important source of food for fish.
23. Hairy Caterpillar - these hairs are numerous and sticky and help to protect the larva from birds.
24. Caterpillar Frightening Colouration - patterns of colour on the rear end of the caterpillar resemble enormous eyes, a bird would think this was a lizard rather than a larva and ignore it.
25. Treehoppers - disguised as thorns on a branch to protect them from predators.
26. Grasshopper - coloured to resemble the grey log (branch) it was resting upon (camouflage).
27. Grasshopper - coloured to resemble the smooth, rounded pebbles it was resting upon (camouflage).
28. Insect on Branch - disguised to resemble brown colour and shape of the living plant it was spotted upon.
29. Praying Mantis - disguised to resemble the trig it was living upon.
30. Leaf Footed Bug - disguised to resemble the leaves and stems upon which it lives.
31. Ladybug
32. Katydid
33. Christmas June Beetle
34. Staghorn Beetle
35. Wood Boring Beetle
36. Goliath Beetles (on a man's forearm)
37. Blue Morpho Butterfly

APPENDIX F – POST-INSTRUCTION INTERVIEW QUESTIONS

POST-INSTRUCTION INTERVIEW QUESTIONS

1. If you had to describe this object (a red potato tuber) to someone who had never seen it before, what would you say about it? If the name is not given in the description, ask: "What do you think it is?"

   Where would you look to find potatoes? If the child answers, "In a garden", ask: "Where is this part of the potato (the tuber) found in the garden? Is it on the ground or hanging on the plant or in the earth?"

   Would you say that this potato is living or nonliving? Why do you think so? If a child in answering any of the preceding questions has already said that it is living or nonliving, ask the following:

   Let's say you were a scientist from another planet and had never seen a potato or potato plant before, but you knew about plants because different plants grew on your planet. Now if you happened to come to Earth, and couldn't speak English, and saw this (potato), what would you do to figure out whether or not it was living or non living? What kind of questions do you think a scientist would ask to determine if this object (potato) is alive or was once alive?

2. Ask the child to name the animals in the order they are arranged on the tabletop. If s/he does not spontaneously mention that they are arranged in a pattern, ask: What can you tell me about this arrangement of animals? If the child says that that animals are arranged in a pattern, ask: What is the pattern that you see? Can you show me the sett? How many times has the sett been repeated to make the pattern? Can you continue the pattern with these pieces?

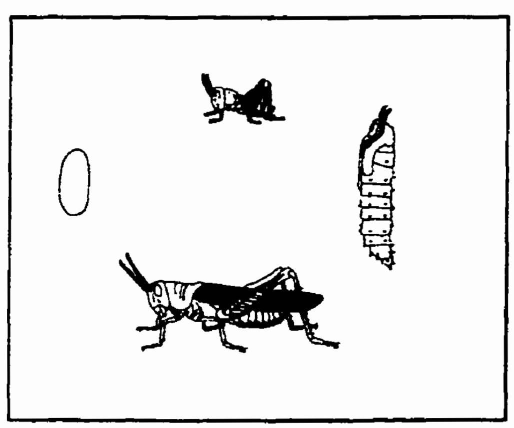
   What could you do to make this pattern into a cycle? Can you show me, and as you make a cycle can you tell me what you are doing to make the pattern a cycle? (What is a cycle? How does it differ from a pattern?)

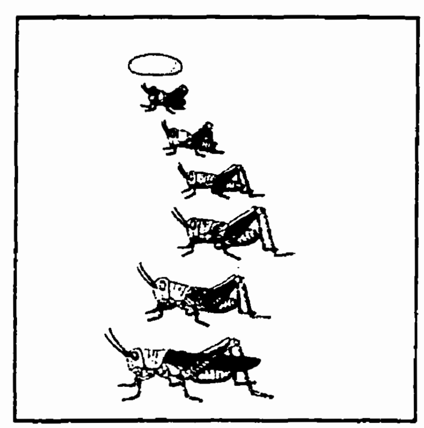
3. I have [randomly] placed nine photographs of adult animals on the tabletop. Could you please put the photograph of each baby animal with its parent? While you are deciding which young animal goes with each adult, can you tell me what you are thinking? If the child is successful, ask: "Why was this so easy for you?" How did you know which baby to pair with each adult parent?

4. I have a model of a desert short horned lizard. You can hold it if you would like. Do you know what group of animals the lizard belongs to (mammal, reptile, amphibian, birds, fish, or insect)?
The lizard is a reptile. Do you remember the two reptiles we talked about during science? (snake and turtle/tortoise) Well, this lizard has a life cycle just like most turtle/tortoises and snakes. Even though we haven't studied the lizard, tell me what you think the lizard's life cycle could be.

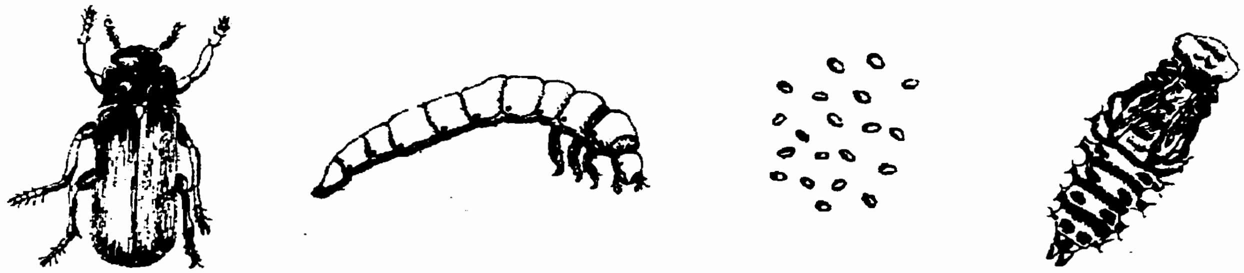
5. I have models of three animals that look a lot like lizards, and many people seeing them for the first time believe that this is what they are. They are not lizards, though. Lizards have scales. The skin of this animal is smooth. Do you know what these animals are called? (salamanders) Do you know the animal group they belong in? (all salamanders are amphibians) Do you remember other animals that we talked about that were also called amphibians? (frog and toad) Even though we haven't studied the salamander in detail, tell me what you think the salamander's life cycle could be.

6. Six weeks ago we read and talked about grasshoppers and crickets. I have a diagram that a friend of mine drew. He was just learning about these insects, and he wanted to do a drawing of the grasshopper's life cycle. Take a look at his diagram. Tell me what you see. What stages has he shown? Point to the pupa and ask, what do you think this might be? If you were his teacher, what would you say to him about the life cycle he has drawn for the grasshopper? If the child sees an error in the diagram, a pupa that shouldn't be in a life cycle without a larval stage, show the corrected diagram and ask if s/he believes it is a more accurate (better) representation of the life cycle of the grasshopper. What is it that makes her/him think it's "better" than my friend's attempt.





7. I have drawings that show the life cycle of a mealworm beetle. I would like you to arrange them in the order that you believe they would occur during the life of a mealworm beetle, and to tell me what you think happens during each stage.



8. Here are a few beetles that I have borrowed from the Entomology Department (pinned specimens). Look at the pairs of beetles that have been pinned side-by-side. They are the same kind of beetle. What do you notice about them? Do they look the same? In what way are they alike? How are they different? If a child mentions size (bigger and smaller) ask, why do you think they are different sizes when they are the same kind of beetle? Do you think they are the same age? Which one is older?