DOCUMENT RESUME

ED 418 777 PS 026 273

AUTHOR	Lind, Karen K.
TITLE	Science in Early Childhood: Developing and Acquiring Fundamental Concepts and Skills.
SPONS AGENCY	National Science Foundation, Washington, DC.
PUB DATE	1998-02-00
NOTE	18p.; Paper presented at the Forum on Early Childhood Science, Mathematics, and Technology Education (Washington, DC, February 6-8, 1998).
PUB TYPE	Opinion Papers (120) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Child Development; Constructivism (Learning); *Early Childhood Education; Fundamental Concepts; Inquiry; Learning Processes; Piagetian Theory; Preschool Curriculum; Science Curriculum; *Science Education; *Science Instruction; Scientific Concepts; Skill Development; Teaching Methods; Young Children
IDENTIFIERS	National Science Education Standards; Vygotsky (Lev S)

ABSTRACT

Efforts to introduce children to essential experiences of science inquiry must begin at an early age. This paper describes the development of fundamental concepts and skills used from infancy through the primary years and presents strategies for helping students to acquire those fundamental concepts and skills needed for inquiry learning. The paper provides an overview of teaching and learning science in the early years, emphasizing the importance of selecting content that matches children's cognitive capacities. During early childhood, children are acquiring fundamental concepts such as: one-to-one correspondence; counting; classifying; and measuring. They also develop processes to apply these concepts and to develop new ones. Children acquire fundamental concepts through active involvement with the environment. Science content can be introduced effectively into naturalistic, informal, or structured learning experiences. Several examples are given to illustrate the natural integration of fundamental concepts and process skills in mathematics and science. It is noted that the national reforms in science education and research support teaching science through inquiry. Several theories underlying early science instruction, including Piaget's and Vygotsky's theories of concept development, and a constructivist approach are explored. The paper notes the importance of considering the child's cognitive capacity when developing science instruction and maintains that when there is a mismatch, children are unable to extend, apply, or interpret deeper meanings of the content, and their interest and positive attitudes are likely to diminish. The paper concludes by noting that cognitive research has identified numerous misconceptions regarding scientific concepts in children and should be considered as barriers that educators need to overcome before approaching new concepts. Contains 24 references. (KB)

SCIENCE IN EARLY CHILDHOOD: DEVELOPING AND ACQUIRING FUNDAMENTAL CONCEPTS AND SKILLS

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Prepared for the Forum on Early Childhood
Science, Mathematics, and Technology Education
February 6, 7, and 8, 1998
Washington, D.C.

Sponsored by Project 2061 of the
American Association for the Advancement of Science
with funding from the National Science Foundation

SCIENCE IN EARLY CHILDHOOD : DEVELOPING AND ACQUIRING FUNDAMENTAL CONCEPTS AND SKILLS

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One of the strongest themes in the national science standards is that all children can learn science and that all children should have the opportunity to become scientifically literate. In order for this to happen, the effort to introduce children to the essential experiences of science inquiry and explorations must begin at an early age.

A national consensus has evolved around what constitutes effective science teaching and learning for young children. Science is understood to be a process of finding out and a system for organizing and reporting discoveries. Rather than being viewed as the memorization of facts, science is seen as a way of thinking and working toward understanding the world. This agreement can be seen in the national reform documents *National Science Education Standards* (*NSES*) (National Research Council, 1996), *Science for All Americans* (American Association for the Advancement of Science, 1989), and *Benchmarks for Science Literacy* (American Association for the Advancement of Science,1993). Both *NSES* and *Benchmarks* are aligned with the guidelines from the National Association for the Education of Young Children (Bredekamp, 1987; Bredekamp & Rosegrant, 1992; Bredekamp & Copple, 1997). More than ever before, educators agree that preschool and primary level science is an active enterprise.

The reform documents mentioned above are based on the idea that active, hands-on, conceptual learning that leads to understanding, together with the acquisition of basic skills, provides meaningful and relevant learning experiences. These documents also emphasize and reinforce Oakes' (1990) observation that all students, especially underrepresented groups, need to learn scientific skills such as observation and analysis that are part of a "less-is-more" curriculum that starts when children are very young.

This paper describes how the fundamental concepts and skills used from infancy through the primary years are developed and describes strategies for helping students to acquire fundamental concepts and skills needed for inquiry learning. An overview of teaching and learning science in the early years is presented, with emphasis on the importance of selecting science content that matches the cognitive capacities of students.

HOW FUNDAMENTAL CONCEPTS AND SKILLS DEVELOP

As any scientist knows, the best way to learn science is to do science. This is the only way to get to the real business of asking questions, conducting investigations, collecting data, and looking for answers. With young children this can be best accomplished by examining natural phenomena that can be studied over time. Children need to have a chance to ask and answer questions, do investigations, and learn to apply problem-solving skills. Active, hands-on, student-centered inquiry is at the core of good science education.

During early childhood, children actively engage in acquiring fundamental concepts and in learning fundamental process skills. Concepts are the building blocks of knowledge; they allow people to organize and categorize information. As we watch children in their everyday activities at various stages of development, we can observe them constructing and using concepts. For example:

- *One-to-One Correspondence*—putting pegs in pegboard holes or passing one apple to each child at the table;
- *Counting*—counting the pennies from the penny bank or the number of straws needed for every child at the table;
- *Classifying*—placing square shapes in one pile and round shapes in another or putting cars in one garage and trucks in another; and
- *Measuring*—pouring sand, water, rice or other materials from one container to another.

Young children begin to construct many concepts during the pre-primary period, including mathematics and science concepts. They also develop the processes that enable them to apply their newly acquired concepts and to enlarge current and develop new concepts. As they enter the primary period (grades one through three), children apply their early, basic concepts when exploring more abstract inquiries and concepts in science and to help them understand more complex concepts in mathematics such as multiplication, division, and the use of standard units of measurement (Charlesworth & Lind, 1995).

As young children grow and develop physically, socially, and mentally, their concepts grow and develop as well. *Development* refers to changes that take place due to growth and experience. These changes follow an individual timetable for each child. Children of the same age may reach certain stages weeks, months, or even a year to two apart and still fall within the normal range of development.

Concepts used in science grow and develop as early as *infancy*. Babies explore the world with their senses. They look, touch, smell, hear, and taste. Children are born curious and want to know all about their environment. Babies begin to learn ideas of *size*:

as they look about, they sense their relative smallness. They grasp things and find that some fit their tiny hands and others do not. Infants learn about *weight* when items of the same size cannot always be lifted. They learn about *shape*: some things stay put while others roll away. They learn *time sequence*: when they wake up, they feel wet and hungry. They cry. The caretaker comes. They are changed and then fed. Next they play, get tired, and to bed to sleep. As infants begin to move, they develop *spatial sense*: they are placed in a crib, in a playpen, or on the floor in the center of the living room. As babies first look and then move, they discover *space*: some spaces are big and some spaces are small. (Charlesworth & Lind,1995).

As children learn to crawl, to stand, and to walk, they are free to discover more on their own and learn to think for themselves. They hold and examine more things. They go over, under, and into large objects and discover their size relative to them. *Toddlers* sort things. They put them in piles—of the same color, the same size, the same shape, or with the same use. Young children pour sand and water into containers of different sizes. They pile blocks into tall structures and see them fall and become small parts again. The free exploring and experimentation of a child's first two years help to develop muscle coordination and the senses of taste, smell, sight, and hearing—skills and senses that serve as a basis for future learning.

As young children enter the *preschool* and *kindergarten* levels of the preprimary period, exploration continues to be the first step in dealing with new situations; at this time, however, they also begin to apply basic concepts to *collecting and organizing data* to answer a question. Collecting data requires skills in observation, counting, recording, and organizing. For example, for a science investigation, kindergartners might be interested in the process of plant growth. Supplied with lima bean seeds, wet paper towels, and glass jars, the children place the seeds in the jars, securing them to the sides with wet paper towels. Each day they add water, if needed, and observe what is happening to the seeds. They dictate their observation to their teacher, who records them on a chart. Each child also plants some beans in dirt in a small container such as a paper or plastic cup. The teacher supplies each child with a chart for his or her bean garden. The children check off each day on their charts until they see a sprout. They count how many days it took for a sprout to appear. They compare this number with those of other class members, as well as with the time it takes for the seeds in the glass jars to sprout. The children have used the concepts of number and counting, one-to-one correspondence, time, and comparison of the number of items in two groups. *Primary* level children might attack the same problem but can operate more independently and record more information, use standard measuring tools, and do background reading on their own.

HOW SCIENCE CONCEPTS ARE ACQUIRED

Children acquire fundamental concepts through active involvement with the environment. As they explore their surroundings, they actively construct their own knowledge. Charlesworth and Lind (1995) characterize specific learning experiences with young children as *naturalistic* (or spontaneous), *informal*, or *structured.* These experiences differ in terms of who controls the choice of the activity: the adult or the child. Science content should be introduced as appropriate, as illustrated in the examples below.

Naturalistic experiences are those in which the child controls choice and action; in *informal experiences,* the child chooses the activity and action, but adults intervene at some point; and in *structured* experiences, the adult chooses the experience for the child and gives some direction to the child's action. Keep in mind that there are variations in learning styles among groups of children and among different cultural ethnic groups.

Naturalistic Experiences

Naturalistic experiences are those initiated spontaneously by children as they go about their daily activities. These experiences are the major mode of learning for children during the sensorimotor period. Naturalistic experiences can also be a valuable mode of learning for older children.

The adult's role is to provide an interesting and rich environment. That is, adults should offer many things for the child to look at, touch, taste, smell, and hear. The adult should observe the child's activity, note how it is progressing, and then respond with a glance, a nod, a smile, or a word of praise to encourage the child. The child needs to know when he is doing the appropriate things. Some examples of naturalistic experiences include:

- Tamara takes a spoon from the drawer—"This is big." Mom says, "Yes."
- Cindy (age 4) sits on the rug sorting colored rings into plastic cups.
- Sam (age 5) is painting. He makes a dab of yellow. Then he dabs some blue on top. "Hey! I've got green now."

Informal Learning Experiences

The adult initiates informal learning experiences as the child is engaged in naturalistic experiences. These experiences are not pre-planned: they occur when the adult's experience and/or intuition indicate that it is time to act. For example, the child might be on the right track in solving a problem but needs a cue or encouragement. Or, the adult might take advantage of a teachable moment to reinforce certain concepts. Some examples of informal experiences are:

- "I'm six years old," says three-year-old Kate while holding up three fingers. Dad says, "Let's count those fingers, one two, three fingers. You are three years old."

- Juanita (age 4) has a bag of cookies. Mrs. Ramirez asks, "Do you have enough for everyone?" Juanita replies, "I don't know." Mrs. R. asks, "How can you find out?" Juanita says, "I don't know." Mrs. R. replies, "I'll help you. We'll count them."

Structured Learning Experiences

Structured experiences are preplanned lessons or activities that can happen in many different ways. For example, Cindy is four years old. Her teacher decides that she needs some practice counting. She says, "Cindy, I have some blocks here for you to count. How may are in this pile?"

Teachers can also offer structured experiences in the following situations:

- With a small group at a specific time. Or, with a small group at a specific time, such as a teacher placing different size balls and asks the children to examine the balls and discuss their characteristics. Mrs. Red Fox picks up a ball and says, "find a ball that is smaller."

- At any opportune time. Mrs. Flores, knowing that Tanya needs help with the concept of shape, suggests a game to play and gives her directions to play the game.

- With a large group at a specific time. Ms. Hebert realizes that classification is an important concept that should be applied throughout the primary grades. It is extremely important in organizing science data. For example, to study skeletons, Ms. Hebert had students bring bones from home to be classified or placed in subcategories.

COMMONALITIES OF SCIENCE AND MATHEMATICS IN EARLY CHILDHOOD

There is a natural integration of fundamental concepts and process skills across content areas, including mathematics and science. When the fundamental mathematics concepts—comparing, classifying, and measuring—are applied to science problems, they are referred to as process skills. That is, math concepts are needed in order to solve problems in science. The other science process skills—observing, communicating, inferring, hypothesizing, and defining and controlling variables—are equally important for solving problems in both science and mathematics.

For example, consider the principle of the ramp—a basic concept in physics. Suppose a two-foot-wide plywood board is leaned against a large block so that it becomes a ramp. The children are given a number of balls of different sizes and weights to roll down the ramp. Once their free exploration defines the ideas of the game, the teacher might ask some questions such as, "What would happen if two balls started to roll from the top of the ramp at the same time?" "What would happen if you changed the height of the ramp? Or had two ramps of different heights? Of different lengths?" The children could guess, explore what happens when they vary the steepness and length of the ramps or use different balls, observe what happens, communicate their observations, and describe similarities and differences in each of their experiments. They might observe differences in speed and distance contingent on the size or weight of the ball, the height and length of the ramp, or other variables. In this example, children could use the mathematical concepts of speed, distance, height, length, and counting (how many blocks are propping each ramp?) while engaged in scientific observations.

In another example, a preschool teacher brings several pieces of fruit to class: one red apple, one green apple, two oranges, two grapefruit, and two bananas. The children examine the fruit to discover as much about it as possible. They observe size, shape, color, texture, taste, and composition using counting and classification skills (How many of each fruit type? Juicy or dry, segmented or whole, seeds or not, and so on). These observations may be recorded (Color? How many are spheres? How many are juicy? And so on). The fruit can be weighed and measured, prepared for eating, and divided equally among the students.

Math and science concepts and skills can be acquired as children engage in traditional early childhood activities such a playing with blocks, water, sand, and manipulative materials, as well as during dramatic play, cooking, and outdoor activities. Providing young children with opportunities to see the math and science in their everyday activities helps them to build the basic understandings and interest for future science and math learning.

ENCOURAGING INQUIRY THROUGH PROBLEM SOLVING

A major area of interest in science education research is the teaching of science through inquiry. The national reforms in science education and research findings overwhelmingly support the concept of teaching science through inquiry. The United States Department of Education and the National Science Foundation (1992) endorse mathematics and science curricula that promote active learning, inquiry, problem solving, cooperative learning, and other instructional methods that motivate students.

National Science Education Standards (National Research Council, 1996) states that science teaching must reflect science as it is practiced, and that one goal of science education is to prepare children who understand the modes of reasoning of scientific inquiry and can use them. *NSES* presents inquiry as a step beyond process learning, such as observing and inferring. In inquiry, children must combine process skills with scientific knowledge as they use scientific reasoning and critical thinking to develop understanding.

Inquiry-oriented instruction engages students in the investigative nature of science. As Novak (1977) suggested, inquiry is a student behavior that involves activity and skills, but the focus is on the active search for knowledge or understanding to satisfy curiosity. Teachers can encourage inquiry through problem solving. As with inquiry, the driving force behind problem solving is curiosity—an interest in finding out. Problem solving is not as much a teaching strategy as it is a child behavior. The challenge for the teacher is to create an environment in which problem solving can occur.

Problems should relate to, and include, the children's own experiences. From birth on, children want to learn and they naturally seek out problems to solve. Problem solving in the pre-kindergarten years focuses on naturalistic and informal learning, which involves explorations and discovery through experiences: filling and emptying containers of water, sand or other substances, observing ants, or racing toy cars down a ramp. In kindergarten and the primary grades, adults can institute a more structured approach to problem solving.

There is a remarkable degree of agreement in the professed beliefs of most science educators—that problem solving and reflective thinking play an important role in children's learning of science in school. In summarizing the findings of twenty-six national reports calling for reform in education—particularly curriculum and instruction in mathematics and science—Hurd (1998) found that eighteen of those reports specifically describe problem solving in science as an educational objective.

The asking and answering of questions is what problem solving is all about. When the situations and problems that the students wonder about are perceived as real, their curiosity is stimulated and they want to find an answer. Searching for a solution to a question or problem that is important to the student holds her attention and stimulates her enthusiasm.

THEORETICAL BASIS OF SCIENCE EDUCATION

The young child's understanding of science grows from the development of fundamental concepts during early childhood. Much of our understanding about how and when this development takes place comes from research based on Jean Piaget's and Lev Vygotsky's theories of concept development (DeVries & Kohlberg, 1987/1990; Driver, Guesne & Tiberghein, 1985; Kamii & DeVries. 1978; Osborne & Freyberg, 1985).

The major view of the constructivist approach is to place the emphasis on individual children as intellectual explorers, making their own discoveries and constructing knowledge. In science, teaching for conceptual change, or "teaching for understanding," requires different strategies from those found in many traditional settings. Instead of memorizing science facts, students are encouraged to use the inquiry process. Science education researchers find that this best done within a developmentally appropriate context that progressively increases in conceptual depth and complexity as children advance through the grades and throughout life. The assessment of prior knowledge is thought to be essential to this process. Von Glaserfeld (1989) and Resnick (1987), and others, caution that if we as educators do not take students' prior knowledge into consideration, it is likely that the message we think we are sending will not be the message received.

The emphasis in science education is not as much on children discovering everything for themselves as it is on relating new knowledge both to previously learned knowledge and to experiential phenomena so that students can build a consistent picture of the physical world. This can be reflected in science teaching in several ways. For example, when children show an interest in learning more about a bean plant or a nearby tree, the teacher should ask questions to determine what the student already knows. In this way, teachers can assess prior knowledge and modify learning experiences and classroom settings to meet student needs.

SCIENCE CONTENT AND COGNITIVE CAPACITY: AVOIDING A MISMATCH

Although evidence of developmental stages of learning (Piaget, 1969) is considered a major contribution from research to the teaching and learning of science, these developmental stages are not always taken into account when designing science curriculum and experiences for young children. If children are to learn science and become scientifically literate, educators must choose appropriate science content and experiences to match children's cognitive capacities at different stages of development. The importance of this match can be seen in research by Cowan (1978), who reports that mismatching content and developmental levels (e.g., expecting kindergarten children to understand the movements of the Earth's crust) leads to misconceptions and frustrations for teacher, parent, and child. These types of mismatches tend to cause teachers to resort to telling the information because the child cannot conceptualize the content. As Covington and Berry (1976) found, the results of mismatched content and cognitive capacity are that (1) children are not able to extend, apply, or interpret deeper meanings of the content; and (2) interest and positive attitudes toward science are likely to diminish. The implication from the research is that the content must always be within the realm of possibility of comprehension. Many examples in the literature emphasize the necessary match between science content and cognitive capacity as essential to learning science.

A prominent feature of cognitive research is the study of student misconceptions in science. These are not merely errors in calculations or misapplication of strategies. They are ideas that are based on individual misconceptions or incorrect generalizations that are consistent with the student's general understanding. For this reason they form powerful barriers that educators must overcome before approaching new concepts. For example, misconceptions can be seen in children's ideas about light and shadows, which have been studied by Piaget (1930), DeVries (1986), and Feher and Rice (1987). Young children think of a shadow as an object or substance and that light is the agent that causes the object to form or that allows people to see the shadow, even when it is dark.

The current interest in the study of science concept learning owes much to the work of Novak (1977). This line of research and the clinical methods used employ Piagetian tasks to explore children's explanations for natural phenomena. Since this work, a large number of studies related to a wide range of topics in the science curriculum have been reported, reviewed, and summarized by many researchers.

In considering all of the preschool and primary developmental stages described by Piaget, keep in mind that a child's view of the world and concepts are not the same as yours. Their perception of phenomena is from their own perspective and experiences. Misconceptions will arise. So, explore the world to expand thinking, and be ready for the next developmental stage. Teach children to observe with all of their senses and classify, predict, and communicate to discover other viewpoints.

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