Dialogue on Early Childhood Science, Mathematics, and Technology Education

First Experiences in Science, Mathematics, and Technology

Science in Early Childhood: Developing and Acquiring Fundamental Concepts and Skills

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One of the strongest themes in the *National Science Education Standards* (*NSES*) (National Research Council 1996) and *Benchmarks for Science Literacy* (*Benchmarks*) (American Association for the Advancement of Science 1993) is that all children can learn science and that all children should have the opportunity to become scientifically literate. In order for this learning 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. More than ever before, educators agree that preschool-level and primary-level science is an active enterprise. 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 trying to understand the world. This agreement can be seen in the national reform documents *NSES*, *Benchmarks*, and Science for All Americans (American Association for the Advancement of Science 1989.) Both *NSES* and *Benchmarks* are aligned with the guidelines from the National Association for the Education of Young Children (Bredekamp 1987; Bredekamp and Rosegrant 1992; Bredekamp and Copple 1997).

The reform documents mentioned in the previous paragraph espouse the idea that active, hands-on, conceptual learning provides meaningful and relevant learning experiences. These documents also reinforce Oakes' (1990) observation that all students, especially those in underrepresented groups, need to learn scientific skills such as observation and analysis at a very young age.

This paper describes how fundamental concepts and skills are developed from infancy through the primary years and offers strategies for helping students to acquire the skills needed for inquiry learning. It provides an overview of teaching and learning science in the early years, emphasizing 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 strategy can best be 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.

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

- *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, expand existing concepts, and develop new ones. 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. Using these concepts also helps them understand more complex concepts in mathematics such as multiplication, division, and the use of standard units of measurement (Charlesworth and Lind 1995).

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. 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 begin to learn ideas of size: As they look about, they sense their relative smallness. They go over, under, and into large objects and discover the size of these objects relative to their own size. They grasp things and find that some fit their tiny hands, and others do not. Infants learn about *weight* when they cannot always lift items of the same size. 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 go to sleep. As babies first look and then move, they discover *space*: Some spaces are big and some spaces are small. With time, babies develop *spatial sense*: They are placed in a crib or playpen in the center of the living room (Charlesworth and Lind 1995).

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 children enter preschool and kindergarten, exploration continues to be the first step in dealing with new situations. At this time, however, children 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 the seeds to the sides of the jars with the 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 their comments 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. Then they count how many days it took for a sprout to appear, comparing 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 they 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 their 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 activity: the adult or the child. *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 groups. Thus, science content should be introduced when it is appropriate to do so, as illustrated in the following examples.

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.

With naturalistic experiences, the adult's role is to provide an interesting and rich environment for the child. 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 or she is doing the appropriate things. Below are some examples of naturalistic experiences.

- Tamara takes a spoon from the drawer and says, "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 puts down a dab of yellow. Then he dabs some blue on top. "Hey! I've got green now," he exclaims.

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 or intuition or both 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. In another situation, the adult might take advantage of a teachable moment to reinforce certain concepts. Some examples of informal experiences follow.

- "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 occur in many different ways. For example, Cindy is four years old. Her teacher decides that she needs to practice counting. She says, "Cindy, I have some blocks here for you to count. How many are in this pile?"

Teachers can also offer structured experiences in the following situations:

- With a small group at a specific time. For example, a teacher shows the children balls of different sizes and asks them to examine the balls and discuss their characteristics. The teacher 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, when it was time to study skeletons, Ms. Hebert had students bring bones from home so they could classify them.

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 fundamental mathematics concepts—comparing, classifying, and measuring—are applied to science problems, they are referred to as *process skills*. These mathematical concepts are necessary to solve some science problems. 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. 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 supporting 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 these pieces 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 no seeds?) These observations may be recorded. (What is the color of each fruit? How many are spheres? How many are juicy?) 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 as 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 learning.

Encouraging Inquiry Through Problem Solving

A major area of interest in science education research is the teaching of science through inquiry. Research findings and the national reforms in science education overwhelmingly support this notion. The U.S. 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. The publication entitled *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 to understand and use the modes of reasoning of scientific inquiry. *NSES* presents inquiry as a step beyond process that involves learning, observing, and inferring.

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 students' curiosity. In inquiry, educators should not expect children to discover everything for themselves, rather, they should focus on relating new science knowledge both to previously learned knowledge and to experiential phenomena, so students can build a consistent picture of the physical world. Science teachers can facilitate this process 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 each student already knows. In this way, teachers can modify learning experiences and classroom settings to best meet individual needs.

One way to involve students in inquiry is through problem solving, which is not as much a teaching strategy as it is a child behavior. As with inquiry, the driving force behind problem solving is curiosity—an interest in finding out. 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, 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: 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.

Most science educators agree that problem solving and reflective thinking play an important role in children's science learning in school. In summarizing the findings of 26 national reports calling for reform in education—particularly curriculum and instruction in mathematics and science—Hurd (1989) found that 18 of those reports specifically identify problem solving in science as an educational objective.

Problem solving can be a powerful motivating factor to learn science. When students perceive the situations and problems they study in class as real, their curiosity is piqued and they are inspired to find an answer. Searching for a solution to a question or problem that is important to the student holds his or her attention and creates enthusiasm.

The Theoretical Basis of Science Education

The young child's understanding of science grows from the fundamental concepts they develop during early childhood. Much of our understanding about how and when this development takes place comes from research that is based on theories of concept development as put forth by Jean Piaget and Lev Vygotsky (DeVries and Kohlberg 1987/1990; Driver et al. 1985; Kamii and DeVries 1978; Osborne and Freyberg 1985). These theories gave rise to the constructivist approach, which places the emphasis on individual children as intellectual explorers who make their own discoveries and construct knowledge. Constructivism has important implications for science education, especially in today's classrooms, where students are encouraged to engage in the inquiry process rather than memorize isolated science facts.

The current interest in the study of science concept learning owes much to the work of Novak (1977), whose book explores children's explanations for natural phenomena. Since this text was published, numerous studies related to a wide range of topics in the science curriculum have been reported, reviewed, and summarized by many researchers.

In science, teaching for conceptual change, or "teaching for understanding," requires different strategies from those previously employed by educators. Many science education researchers agree that the key is to provide a developmentally appropriate context that progressively increases in conceptual depth and complexity as children advance through school and life. The assessment of prior knowledge is thought to be essential to this process. Von Glasserfeld (1989), 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 that students receive.

Science Content and Cognitive Capacity: Avoiding a Mismatch

Although Piaget's (1969) developmental stages of learning are considered a major contribution to the teaching and learning of science, educators and curriculum developers do not always take these stages 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 their development.

Cowan (1978) underscores the importance of this alignment, stressing 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 often cause teachers to resort to telling the information in a didactic manner 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. Many other examples in the literature also emphasize the match between science content and cognitive capacity as essential to learning science. The implication from the research is that the content must always be within the realm of possibility of comprehension.

A prominent feature of cognitive research is the study of student misconceptions in science. These misconceptions are not merely errors in calculations or the misapplication of strategies. They are ideas that are based on misperceptions or incorrect generalizations that are consistent with the student's general understanding of a phenomenon. For example, misconceptions can be seen in children's ideas about light and shadows, which have been studied by Piaget (1930) and Feher and Rice (1987). Young children think of a shadow as an object. They think that light is the agent that causes the object to form or that allows people to see the shadow, even when it is dark. This example clearly shows that misconceptions are a very real and significant obstacle to learning, one that educators must overcome before broaching new science concepts.

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 of scientific and mathematical concepts is not the same as yours. Their perception of phenomena is formed from their own perspective and experiences. Misconceptions will arise. So, be ready to explore the world to expand their thinking, and be prepared for the next developmental stage. Teach children to observe with all of their senses and to classify, predict, and communicate, so they can discover other viewpoints.

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