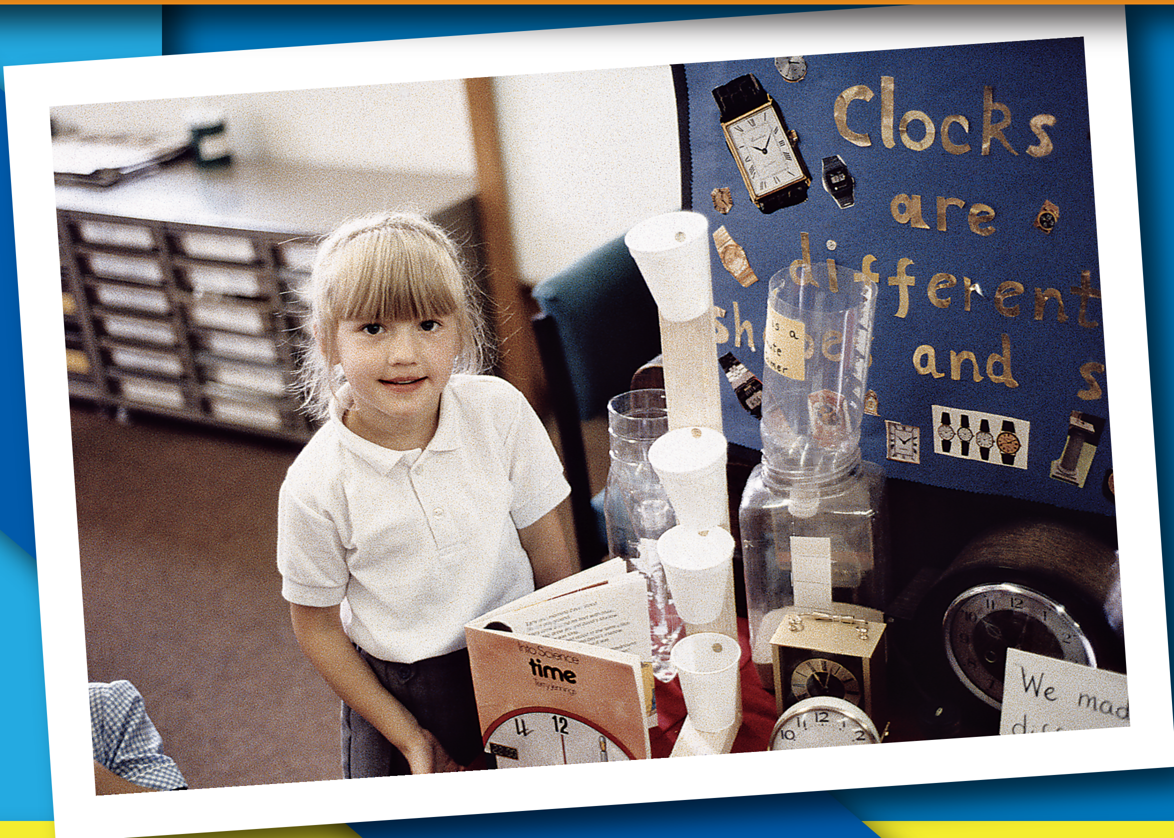
I DO, AND I UNDERSTAND

Helping Young Children Discover Science and Mathematics



Robert Louisell

with special guest chapters by

Stephen Hornstein and Peter Frost

I hear, and I forget.
I see, and I remember.
I do, and I understand.

*Ancient Asian Proverb.

I DO, AND I UNDERSTAND

Helping Young Children Discover Science and Mathematics

Robert Louisell

with special guest chapters by

Stephen Hornstein
St. Cloud State University

and

Peter Frost

Constructivist Press
Minneapolis, Minnesota

For information about this book, contact:

Constructivist Press
P.O. Box 24502
Minneapolis, MN 55424
www.constructivistpress.com

Cover photos by Robert Louisell

Book layout, design, and typesetting
by Peter Lilliebridge

'Cross the Lilliebridge™
www.crossthelilliebridge.org

Printed by
Sunray Printing Solutions
in St. Cloud Minnesota

SUNRAY
PRINTING SOLUTIONS
www.sunrayprinting.com

10-digit ISBN 1-934478-36-9
13-digit ISBN 978-1-934478-36-3

Printed in the United States of America

7 6 5 4 3 2 1

Contents

Author's Preface

I hear, and I forget.
I see, and I remember.
I do, and I understand.

— Ancient Asian Proverb

There are many ways that young children learn. They learn from observing. They learn from actively listening and from overhearing. Most of all, they learn from doing. This book has been written for future teachers of young children; that is, students of early childhood education or child development. It has been specifically designed for use in courses on how to teach young children about mathematics and science.

A young child's thoughts are intricately tied to her or his actions because the young child's thoughts have not yet been fully distinguished from the young child's actions in the child's mind. Chapters 2 and 3 attempt to explain why this is so. Some education texts include a chapter on children's "misconceptions," as does this text, but, as far as we are aware, no text actually deals with appropriate strategies for interviewing children and interpreting what they say. Chapters 2 and 3 were written to help prospective teachers of young children learn how to better get to know the ideas of the children with whom they work. This is an essential skill for constructivist teachers since they must anticipate, and respond to, the ideas of their students.

But the whole point of this book—its theme—is that young children best learn about math and science by *do*ing. What does that mean? *Do*ing? It means that they learn how to add by combining groups of objects and counting how many objects there are in the new group that has been formed as a result. It means that they learn about density by making clay boats and testing them to see if they float. It means learning about electricity by being given a battery, a bulb, and a wire and figuring out how to make the bulb light. It means learning how to divide by taking a group of objects—say, caramels—and dividing them equally among themselves.

In other words, young children need to *experience* mathematics and science if they are to learn it well. And they need to *understand* these experiences. Children can learn the procedure for addition—combining two or more groups of objects and counting up the result—but they must also understand this process! When it comes to the written symbols for mathematics, the child must realize that two or more groups are being combined every time she sees a "+" sign.

A child's curiosity must be nurtured during instructional experiences with math and science. Telling children the answers to science questions and showing them the most efficient ways to solve math problems does not nurture their curiosity about these subjects. If you always answer the child's questions about science, what reason does she have to explore these phenomena further? If you always show the child how to solve math problems, when will she ever develop her *own* ideas about math? We don't mean that a teacher should never show a child how to do something like add or subtract or that a teacher should never tell the child an answer to a science question, but this sort of showing and telling should be done sparingly. Mathematics and science must also be related to the real life experiences of children. Otherwise, how will young children ever become aware of the importance of math and science in the world in which they live and observe things? Why will children want to learn about math and science? They must see how it applies to their everyday lives. Chapters 10 and 11 deal with this issue—how math and science are related to our everyday lives as well as how they relate to other subjects.

Our philosophy of teaching science and mathematics to young children is constructivist (See Chapter 1 for our interpretation of this term). Some people think that knowledge can be transmitted—*taught*—to children. We believe, as Piaget did, that the young child *invents* her or his knowledge and understandings. Teachers can facilitate this process of invention through a variety of methods; for example, by providing young children with hands-on experiences and engaging them in discussions and debates about these experiences. Children come to school curious about many things, including science and mathematics. It's a shame that they often leave school less curious about these things because we see the development of the child's curiosity as a primary goal—an essential standard—for school science and mathematics.

Although most textbooks of this type typically start with theory and move to examples of best teaching practices, the first three chapters of this book may have "more than enough" theory for some! Professors may choose to deemphasize these chapters, although I do hope that they will at least engage their students in the activity of doing clinical interviews with children. In my own experience as a college professor, it provides early childhood majors with a much needed insight into the differences between how children and adults think. As my doctoral advisor, Jack Easley, said to me many times, the most practical idea is to have a good theory.

We wrote this book because previous texts on the subject of early childhood mathematics and science teaching omitted an essential aspect of the field. While they covered preschool and kindergarten years, they neglected the mathematics and science teaching for grade levels one through three. This book corrects that fault. It comprehensively deals with preschool/kindergarten *and* grades 1–3 and it contains over a hundred tested early childhood activities for mathematics and science. The *Activities for Children,* which are numbered in each of the chapters that include them, are intended for teacher-candidates as well as children. It is appropriate to demonstrate these during class time or to have students practice these activities independently. It is assumed that the practicing teacher will make her own judgement about whether any individual activity is best completed as a teacher-led, supervised activity or as an independent activity for children in small groups. In most cases, this should be obvious from the description of the activity.

There are a variety of boxed items in this text which have been provided for the benefit of the reader. These include *Activities for Children, Activities for Future Teachers, and Assessments.* It is assumed that the reader of this text will keep a student journal related to the activities for future teachers in the science-related chapters. Those *Activities For Future Teachers* that are science-related may be carried out independently by the reader at home or in class with other students, depending on the instructor's preference. We have also included boxes for relevant content standards; for example, NCTM *Principles and Standards, Benchmarks for Science Literacy, National Science Education Standards,* and *Next Generation Science Standards.*

In the chapters about the development of the child's understandings of mathematics (Chapters 4–6), you will find boxed items entitled *Assessment Activity;* for example, *Assessment Activity 4.1.* These are not intended as summative assessments. Rather, they should be considered formative in nature; that is, they are snapshots of "where the child is" in his or her development for this specific math topic at this particular point in time. No inferences about the child's capabilities in mathematics are appropriate here. Rather, these assessments are provided to help teachers acquire some insight into the child's ideas about this topic at a particular point in time so that the teacher can better decide how to teach this child.

Our philosophy of assessment favors authentic assessments for formative purposes. In other words, we believe that assessments should occur in the context of ongoing experiences in which the children are engaged. Reports about the educational progress of individual children should communicate what the child has learned, is learning, and is about to learn. We oppose grades or marks that compare students to each other, except for very general developmental "landmarks" that can help a parent to understand the nature of a child's special needs. We have not included any of the diagnostic assessments used for purposes of special education because many early childhood education programs are now combined with special education and courses in this area can deal more appropriately with this topic. We have, however, included some adaptations for special needs students in science during kindergarten and the primary grades.

We have opted for specific assessments in the form of boxed items rather than for dealing with the entire topic of assessment in a separate chapter on the topic. Readers who would like to know more about strategies for assessing the student's learning during early childhood and elementary school can be referred to Chapter 7 of our previous book, *Developing a Teaching Style–2e,* by Louisell and Descamps (Waveland Press, 2001).

Many future early childhood teachers are unconfident about their own knowledge of science content. The *Activities for Future Teachers* in Chapters 7–9 provide the reader with experiences that will help them develop knowledge related to content that they must teach in the primary grades; for example, *organisms* and *life cycles.*

Appropriate *internet resources* are provided throughout the text in the context of the topics being discussed. A DVD accompanies this text. As this book goes to press, it contains some examples of interviews with children. We hope to include videotapes from classroom math and science lessons, along with an introductory presentation about constructivist teaching, with the second printing.

This book represents the ideas of the primary author about the theory and practice of teaching science and mathematics to young children. He has developed these ideas over a period of over 40 years while teaching children and future teachers. He has tested almost all of the *Activities for Children* with classrooms of young children. We hope you will find this book useful.

Robert Louisell
rlouisell@stcloudstate.edu

References

Louisell, Robert, and Jorge Descamps (2001). *Developing a Teaching Style–2e.* Prospect Heights, IL: Waveland Press.

Acknowledgements

When it was still in its early stages, Jack Mayala and Wally Ullrich reviewed Chapter 2. Frank Kazemek reviewed it at a more developed stage, as did Klaus Witz and Juan Pascual-Leone. Thanks to each of these persons for their constructive feedback.

A number of people reviewed Chapter 3 for me: Frank Kazemek, Muhammad Pervez, Louis Smith, Jan Boom, and Ullrich Müller. This was a difficult chapter to write (and read) and I'm grateful for the feedback I received from each of these people.

Marie Wardrop Louisell, a mathematics educator and my wife, reviewed Chapters 4, 5, 6, and 10. I made several changes based on her comments. She also drew sketches for Figures 9.6–9.9. I'm grateful for all of her labors.

Juan Pascual Leone reviewed Chapter 7, along with the section on constructivism in the first chapter. Frank Kazemek and Ken Kelsey also reviewed the section on constructivism at an earlier time.

Sally Benekee shared her thoughts, expertise, and essential references with me regarding project work.

Several of our graduate students generously shared their ideas and journal entries with us. They are credited in footnotes at appropriate places in the text.

I'm also grateful to Rebecca Louisell, my daughter, who completed the majority of the original illustrations and edited and organized the videos for the DVD that accompanies this book.

Peter Lilliebridge did the design and prepress work for the entire book, including the cover design—developing the icons for the *Activities* boxes, reworking several of the drawings used as illustrations, creating many of the figures, and editing or retaking photos. The quality of this work was stellar and the book's appearance is chiefly his doing.

Sunray Printing Solutions delivered the high quality printing and finishing of the book's pages and cover. They also provided the ISBN number for the book.

I'm also grateful to Julie Tangeman of Minneapolis Public Schools for allowing me to use the district's science center to consult various teachers' guides for early childhood science programs.

Frank Kazemek, Bob Stake, and Judith White provided me with much needed moral support during the period that I was writing this book. Their support helped motivate me to persist to the book's conclusion.

Photos for the book came from Wiltshire and Bristol in England and from graduate students in the early childhood education program at University of Texas, El Paso.

The book would not have been complete without the contributed writings of Steve Hornstein and Peter Frost. Their names also appear on the book's cover.

Finally, the ideas of Jack Easley, who is deceased, about children's thinking and the process of science and math education, influenced this textbook profoundly. I owe him a debt I never can repay!

Chapter 7

How We Should Teach Young Children about Science

I hear, and I forget.
I see, and I remember.
I do, and I understand.

— Ancient Asian Proverb

How can we best help young children to learn about science? How can we nurture the curiosity of children and facilitate learning that fully engages and responds to their natural motivation? That is the topic of this chapter. In this chapter, we plan to review our "laws" of science teaching—the principles that we recommend teachers of young children follow in order to be successful at helping young children to learn about science. We will also explain the role of science processes in learning about science; that is, how young children naturally think like scientists when they learn about science topics. We will also discuss some of the important science curricula developed for young children and share the recommended structure of a science lesson for young children; that is, a format for a lesson plan. Finally, we will discuss the impact of today's content standards for science on the teaching of young children.

Our "Laws" of Science Teaching [1]

In Chapter 2, we drew several implications for how science should be taught. We based these implications on what we know about the young child's conceptions of science and also on our existing knowledge of how young children learn about science. In the first part of this chapter, we will review some of these implications. We have playfully called these "laws" because scientists often come up with laws governing physical forces such as gravity, motion, buoyancy, and thermodynamics. We think of them as principles to consider when one is teaching science.

Children Have Their *Own* Ideas

From the many ideas that children expressed in Chapter 2 about the moon, clouds, shadows, and so on, it should be clear that young children have ideas about science topics that are different from those of adults. A teacher can deal with this challenge in different ways, and some of these ways will result in more successful learning than others. For example, you might try to correct the child and tell them the scientifically accepted understanding. You might, for example, tell the child "The moon doesn't really follow you. It's just so very far away—about 240,000 miles—that it *looks* like it's following you." But this approach has several problems when you consider what we know about how children learn. First, it sends a message to the child that her own ideas are incorrect and shouldn't be considered. Is that the message that you want your students to get from you? Second, there is nothing about your response that the child can relate to her own experience. The moon *looks* like it is following her. When you tell her that it *only* looks like it is following you, will she discard her existing idea?

If the child were talking about what makes things float, and she told you that light things float, you could give the child a container of water and a variety of objects—some heavy and some light, some made of wood and others made of metal, and so on—and tell the child to experiment with the objects and note which ones sink and which ones float. But you can't tell a child to travel to the moon and find out why it looks like it is following her! The best approach in this case is probably to engage the child in conversation about the moon; that is, to extend the conversation in much the same way as a clinical interview, always accepting what the child says—never correcting her. This sends another kind of message to the child—that you can always be trusted to listen to her or his ideas. Engaging young children in conversation about whatever they have observed is an essential act of teaching. You've probably heard people say that the role of a constructivist teacher is not so much to teach as to facilitate learning on the part of the child. Whenever a teacher thinks of teaching as "telling"—as sharing information with the child—they are thinking about teaching in a non-constructivist way; that is, they are not acknowledging that children have their own ideas and that they invent or construct new ideas by applying their existing ideas to their experiences.

We might wonder, also, what is the effect of telling a young child that her or his idea is wrong. Will she or he be likely to share her ideas with you in the future? As Eleanor Duckworth has said "Wrong ideas... can only be productive. Any wrong idea that is corrected [by the child][2] provides far more depth than if one never had a wrong idea to begin with" (Duckworth, 1987, p. 71).

Start With the Child's Ideas

When planning instructional activities for young children, it's best to start with the ideas, interests, and questions of the children. Young children have their own questions that reflect their own ideas. Suppose, for example, that you have just returned to your home with your spouse and children at night. You all get out of your car and look at the night sky. The moon is shining brightly and you can see that it's a quarter-moon, so you say "Oh, look at that! It's a quarter-moon tonight!" Your 7 year-old daughter says "I wonder how they get it to do that?" You ask "Do what?" She replies "Half-moon and quarter-moon and stuff like that..."[3] This question reflects artificialist thinking (See Chapter 2 for more on this topic). It also reflects the child's honest thinking. How does one "start with" this child's ideas when developing curriculum?

One way would be to develop a project unit (See Chapter 11) about the night sky. It might include some night-time activities such as observing the moon through binoculars or a telescope. Perhaps this would cause the child to question her ideas about what we observe in the night sky. But possibly, it wouldn't. Either way, the instructional activities will have facilitated further development of the child's ideas and questions.

There are also a variety of curricula which have been developed in response to the questions and interests that young children have typically expressed. The *Elementary Science Study (ESS)* which is discussed in another section of this chapter, was developed in this way. When a teacher uses this curriculum, or others like it, she can be confident that she is starting with the ideas of young children.

Of course, starting with the child's ideas can be in direct conflict with other articulated objectives for teachers of young children. For example, the content standards articulated by the district or the state may not relate to the ideas of the young children whom you teach. We will discuss content standards in a later section of this chapter.

Actions and Ideas Are Closely Related In the Mind of a Young Child

Think about the conservation of number interviews discussed in Chapters 1 and 4. The simple action of spreading out a row of cubes may lead a young child to conclude that she has more cubes! Or reflect on the child's observations of the moon and her conclusion that it is following her. So many of the young child's ideas are intimately connected with her actions and observations. According to Piaget, this is because young children don't fully distinguish between their actions and thoughts during this stage of development. Given this aspect of the young child's thinking, how can we best proceed in teaching them about science? It's *actions* that most influence their ideas—*not* whatever we tell them! The young child's ideas are in a state of creative and frequent flux. Rather than try to impart specific bits of knowledge to them, we will do better to provide them with experiences that cause them to reflect upon their own ideas.

If we really want to stimulate thinking about science among young children, we will have to provide them with opportunities to perform actions and make observations because performing actions and making observations is how they go about learning during this stage of their lives. Manipulating materials helps children to develop their ideas about physical science. If we provide hands-on situations for children—for example, exploring density by testing out which objects sink and float or learning about electricity by experimenting with batteries, bulbs, and wires—they will reflect on the science phenomena which they observe and develop their own ideas about them. And having ideas is what science is all about!

Don't Pretend to be an Expert

As teachers of young children, we do have an obligation to become as knowledgeable as we can about matters of science. But we *can't* be experts about science, and we shouldn't pretend to be experts. Often enough, we're not even sure that our own ideas about science are correct. This shouldn't embarrass us. In fact, science is so specialized that most scientists do not understand much of the science which takes place outside their own narrowly specialized fields. We're not supposed to be "all-knowing." We're supposed to show our curiosity, wondering about our world and asking questions about it instead of being an authority to whom our students turn for answers. We should help them to figure out the answers to questions which *they* are asking. We should frequently appear puzzled, ask questions, and behave the way people who are curious about their world behave. In sum, we should learn *alongside* our children; not tell them things we find in a teacher's guide or encyclopedia or at an online site—things that we don't fully understand ourselves!

Our job as teachers is to foster curiosity among children—not to supply them with answers. Children come to school curious. They have no "science anxiety" when they enter school. By the end of their elementary school years, however, many children have acquired anxiety about science and math. As teachers, we contribute to science anxiety by behaving as experts or introducing technical terms without providing experiences through which children can come to understand these terms. We also contribute to science anxiety by focusing on correct answers. This makes students afraid of making mistakes and asking "dumb questions." Too often, we teach children to rely on the textbook and the teacher for answers to science questions and to distrust their own ideas. This inhibits their curiosity and they gradually come to see science as something that has nothing to do with their own world. Instead, they view science as something that is only studied in school, in boring ways, until they memorize information so they can regurgitate it on tests.

Explanations Are Ineffective at Helping Young Children Understand Science

The explanations included in textbooks and the verbal presentations of teachers are, at best, ineffective in helping young children to understand science. A famous study of science instruction in the elementary grades found much evidence that children learned in *hands-on* science programs. However, it also found little evidence that they learned from lectures or from reading science textbooks (Shymanski, Kyle, and Alport, 1983, and Shymanski, Hedges, and Woodworth, 1990). When it comes to learning about science, explanations seem to be a poor match to the thinking processes of young children. Instead, children need to perform actions, observe what happens, and reflect on these observations in order to understand science concepts. As the old proverb goes "I hear, and I forget. I see, and I remember. I do, and I understand." In fact, children often misunderstand science concepts because of the explanations which they have been given! Many of us are still holding on to misconceptions which we developed as children. More explanation, in the form of examples in textbooks, demonstrations, and teacher talk will not help clarify these misunderstandings.

Science Is Complex— Don't Try To Make It Simple

Science is complex. Its questions demand logical, creative, and *thorough* thought. Science is *not* a collection of irrefutable facts. Scientists argue, publicly and privately, orally and in writing, about their results, conclusions, and theories. But, when they present their findings in textbooks for non-scientists, they present them as neat, clean, organized pieces of information. Consequently, we have come to see science as facts and explanations (even though we often can't understand them!). We feel incompetent in the world of science.

If science is complex, it is also messy and controversial. It's okay for teachers and children to be puzzled and disagree about explanations of scientific topics. After all, scientists proceed in the same way through their publications and presentations at conferences! When teachers appear to be certain of their own knowledge about science, they inadvertently discourage their students from learning through active exploration and questioning. Science has traditionally been taught as a collection of facts to be memorized. This factual tone implies a strong degree of certainty. There is certainly no need to ask questions if it is all that "cut and dry." But, as we have already said, science is actually very controversial—not at all cut and dry (Easley, in Duckworth et al, 1990). When science is taught so that students must work out their own solutions (rather than be told the "right answers"), students are interested and learn.

Research has been demonstrating that people who challenge and question the principles of science remember these principles better than people who learned these principles more passively.[4] Children are told, for example, that gravity pulls things down to earth. When a child points out that grass grows up or asks "Then, how do airplanes fly?", teachers are usually surprised because they don't understand the principles that well themselves (Easley, 1990, p. 61–65). They often discourage students from asking about these counter-examples. Teachers need to become comfortable with their lack of expertise, and explore with their students the questions that they raise. Instead of discouraging young children from asking questions, young children must be encouraged to challenge and question scientific principles. This helps them to better understand the phenomena which these scientific principles are meant to explain. As teachers, we need to find ways to encourage children to challenge the explanations about science to which they have been exposed.

Science Processes

Knowledge changes often in many areas of science. For example, the smallest indivisible particle of matter was once thought to be the molecule. After that, it became the atom. After that, electrons. Then, a host of different particles were labeled and considered to be the smallest, indivisible particles of matter. Since the 1980s, quarks (which include protons, neutrons, and other types of matter) and leptons (which include electrons, neutrinos and other types of matter) have been considered to be the smallest, indivisible particles, but there may be new discoveries in the future. For this area of science, which is called particle physics, it is likely that factual knowledge will continue to change.

Thus, if you were to teach a child during elementary school that the smallest, indivisible particles of matter are the quark and the lepton, it is entirely possible that this knowledge would become incorrect by the time that this child entered middle school or high school. Suppose you used a traditional approach to science teaching and you required that your children in grade three memorize this fact: The smallest, indivisible particles of matter are the quark and the lepton. Several years later, this child might enter middle school and her teacher might ask her to answer the question "What is the smallest, indivisible particle of matter?" If this child were a bright student and had a good memory, she might give an answer that has become incorrect since the date when she was taught it. It may have been correct when you taught it to her, but it very well might have changed since then!

A group of science educators and scientists grappled with this problem during the 1960s. They asked "What should we teach our children, given the current rate of change in science knowledge?" and they came up with an interesting conclusion. They concluded that, although the facts may often change for science content, the *processes* that scientists use as they go about their work remain essentially the same for centuries. For example, scientists make observations and collect data. They sometimes generate hypotheses and they devise experiments to confirm or reject their hypotheses. They control variables that could influence the results of their experiments. We call these types of thinking "processes" but that is really an abbreviation for "thinking processes."

Refer back to the discussion of *Bloom's Taxonomy of Educational Objectives* (1956) in the Preface to Chapters About Teaching Mathematics and Science to Young Children. It classifies learning objectives into 6 levels. From lowest to highest, these are: knowledge,, comprehension, application, analysis, synthesis, and evaluation.[5] The first level, *knowledge*, is primarily concerned with factual knowledge and information. It is often referred to as "lower-level" knowledge to distinguish it from other types of knowledge which require more thought. The second level, *comprehension*, is concerned with the learner's understanding of lower-level knowledge; for example, knowing the meaning of a particular word. The third level, *application*, is concerned with the learner's ability to translate the first two levels into practice. For example, a learner might understand the difference between feet and inches, but measuring the width of the top of a table in feet and inches is an application of that understanding. Taken together, these first three levels of *Bloom's Taxonomy* can be considered to be the levels that have to do with "content." That is, the lowest three levels deal with the recollection, understanding, or application of content knowledge. In contrast, the highest three levels—analysis, synthesis, and evaluation—are not directly related to content. Rather, these levels are related to thinking processes that analyze, synthesize, or evaluate content knowledge. Sometimes these higher three levels of *Bloom's Taxonomy* are referred to as "higher-order" thinking skills. The chief point we would like to make about *Bloom's Taxonomy* is that there are three levels that deal with "content knowledge" and three levels that deal with "thinking processes." See Figure 7.1 for a graphic representation of this.

As we said, science educators decided it was best to emphasize the thinking processes of scientists and to deemphasize the factual content in science since the content changes so rap-

Bloom's Taxonomy of Educational Objectives

PROBLEM-SOLVING ***PROCESSES***

Higher-Order Thinking

Level 6: Evaluation
Level 5: Synthesis (thinking, problem solving, processes)
Level 4: Analysis
Level 3: Application
Level 2: Comprehension (learning, concepts, skills)
Level 1: Knowledge

Lower-Level Thinking

CONTENT

Figure 7.1

idly. In terms of *Bloom's Taxonomy,* we would say that the people responsible for developing curricula decided to change the focus of science education for children. In the past, the emphasis had been on remembering and understanding science content. Especially in the elementary grades, it's now considered best to emphasize the higher level thinking processes (the ones that scientists make use of) at the expense of content. It doesn't mean that children shouldn't learn *any* content. To use science processes, young children must be exposed in some way to content. One can't think about nothing! But it's believed that children will become comfortable with science by getting to know the "territory" of science; in other words, by getting to know what scientists *do* by investigating science phenomena the way that scientists do. Put another way, while it was common in the past for elementary schools to require children to remember the factual content of science, the goal of science education for children today is more balanced between science processes and factual content. In some programs, science processes predominate over factual knowledge of science content. We will discuss some of these programs in a later section of this chapter. We would say that a good early childhood science education program nurtures the child's wonder in the same way that a scientist's investigations nurture a scientist's sense of wonder.

Of course, some of the processes that scientists use are too advanced for young children. They are developmentally inappropriate as instructional goals. Others, however, are a good match to the young child's typical capabilities. In fact, some of these "basic" processes can be used by very young children at the preschool level. In the next two sections, we will discuss these basic processes as well as some of the processes that are developmental mismatches for young children.

Basic Science Processes Considered Appropriate for Young Children

There are a variety of basic science processes that young children can become engaged in; for example, observing, classifying, communicating, measuring, and, making predictions. We will briefly describe each of these processes and give examples of how young children may use them in science activities.

Observing: Young children are constantly observing. They observe the science phenomena in their world just as they observe social interactions. As young "scientists," they should be encouraged to observe more thoroughly. For example, you might invite a group of 4–5 year olds to observe a butterfly and try to paint one. Tell them to be sure to get the spots and markings. That kind of careful observation is the type of observation that scientists (and painters) must often do. The following activities are examples of things to do with young children to nurture their observation skills. Chapter 8, which specifically deals with activities designed to develop a preschooler's understanding of science, will also share several activities which require the child to use her or his observation skills.

Activity for Future Teachers 7.1

(With live organisms)

It's important that you learn as teachers of young children not to be too squeamish about working with live organisms. Otherwise, you might transfer your nervousness about organisms to your students. For example, if you don't like handling worms with your fingers, then use a suitable substitute like a pen, a pencil, or a hairpin. Acquire a small collection of live organisms such as mealworms, wax moths, or fruit flies. Mealworms can typically be purchased at a pet store. Depending on the season, wax moths can be found at a bait shop. Fruit flies can sometimes be captured from your kitchen and placed in clear vials. Place appropriate food in the container that you keep them in; for example, cereal along with pieces of apple or banana for the mealworms, or honey for the fruit flies. Clear plastic containers used to sell small portions of food (such as pies or sandwiches) are ideal for mealworms or wax moths. Be sure to punch holes in the tops of the containers so the organisms can breathe (You can put porous tape over the top of the containers for fruit flies). Observe your collection of organisms for a few weeks (That's how long it takes for larva to reach the adult stage). Use a magnifying glass as well as your naked eye. You should eventually be able to observe examples of the following stages within the life cycle of your organism: an egg, a larva (worm), a pupa, and an adult. In the case of the fruit flies, the eggs are extremely small. They look a bit like a grain of sugar—only more oval—and can often be observed on the walls of your vials. The adult wax moths can fly. The adult mealworms can jump and can sometimes fly for short distances. Pupas are inactive and usually have a coating and coloration to help protect them and hide them from predators. Although they are typically dormant, you can touch the pupa of a mealworm and it will shake violently before it goes back to its inactive state. Record your daily observations of these organisms in your journal.

Activity for Children 7.1

(With live organisms)

Give each group of 4 children a collection of live organisms such as fruit flies, mealworms, or wax moths. Provide enough magnifying glasses for each child to have her or his own. Ask them to try to find examples of the following: eggs, larvae, pupas, and adults. Have the children observe these organisms each day for about 5–10 minutes.

Activity for Future Teachers 7.2

Take time to observe the moon over a period of time of at least 28 days. Record your notes of these observations and include any drawings which help you to communicate what you observed. Share your observations with the other students in this course.[6]

Classifying: We have already discussed classification as an intellectual capability in previous chapters, especially in Chapter 4's discussion of classification and class inclusion. But science topics are replete with opportunities for classification and many areas of science depend upon classification for organization of their knowledge bases.

Activity for Future Teachers 7.3

Obtain a small collection of rocks from backyards, school grounds, building supply and gardening stores, or shops specializing in rocks and minerals.[7] Spend about 15 minutes examining each rock. Also, use a magnifier to observe each rock's structure more closely. You may want to devise a chart to help you distinguish these rocks from each other and to refer to when communicating with others about them. Share your observations about the characteristics of each rock with the other students in your early childhood methods of science teaching class.

Activity for Children 7.2

Distribute a variety of either white or black rocks to groups composed of 4 children (approximate ages 8 and higher); for example, white rocks such as kaolinite, quartz, calcite, feldspar and marble or black rocks such as anthracite coal, magnetite, graphite, and galena. Make sure that each group has only white rocks or only black rocks. Tell the children to figure out how to tell each of the rocks apart. Color won't be much help to them since all the rocks for their group will be of one color. Have them show their rocks to the rest of your class of children and communicate to the other children their ideas about how to tell these rocks apart.

Activity for Children 7.3

Have a "collections" day! Invite children to bring their own collections and provide some of your own. Collections might include dolls, GI Joes, spoons, baseball cards, stickers, coins, marbles, shells, stamps, hardware, rocks and minerals, buttons, animal figurines, and leaves (during the autumn). Have the children sort them into their own categories based on whatever makes sense to them. Ask them why they have sorted these things in this way.

Counting and Measuring: There are many thinking processes and skills which are used in both science and mathematics. For example, scientists often depend upon precise measurement and quantification, and mathematics is applied in fields like engineering and architecture. The connections between mathematics and science—and between mathematics and the world—are one of the ten standards (goals) identified by the National Council of Teachers of Mathematics.[8]

STANDARDS

Connections: Instructional programs from prekindergarten through grade 12 should enable all students to—

- Recognize and use connections among mathematical ideas
- Understand how mathematical ideas interconnect and build on one another to produce a coherent whole
- Recognize and apply mathematics in contexts outside of mathematics.

Source: National Council of Teachers of Mathematics, Principles and Standards (2000)

Young children like to count things; for example, how many mealworms in the container, how many tiles on the floor of the school's hallway, or how many fish in the aquarium.

Activity for Children 7.4

(Clay Boats, ages 6–8)

Give each child a ball of oil-based clay[9] and a container of water. Tell them to see if they can make it float. In other words, their task is to make a clay boat. Children will explore ways to shape the clay and then test its floatability in the water. Within 20–40 minutes, some children will be successful. Repeat the activity for 2–3 days, allowing 30–60 minutes for the activity plus clean-up time. When individual children have succeeded in making a boat that floats, ask them how many pennies it holds. Challenge them to see who can make the boat that holds the most pennies. This activity combines the need to count with the task of making a good boat, which requires them to develop understandings related to density, specific gravity, and boat construction.[10]

When exploring pendulums, children might count how many times per minute the pendulum swings back and forth while comparing the effects of different pendulum lengths or weights with each other. However, this is something that is rarely initiated on the part of a young child before grade level 3 because it involves coordinating two types of measuring—counting and timing.

We have already discussed *measuring* in some depth in Chapter 6. But which kinds of measuring opportunities are available in early childhood science activities? Measuring temperatures can be interesting for older children who are still in the early childhood stage; for example, taking the outdoor temperature readings as part of their daily weather observations.[11] Times that the temperature readings are taken should also be noted and recorded by the children who do the temperature readings for that day.

Activity for Children 7.5

(Ice Cubes and Water, Ages 7 and up)

Have the children fill ice cube trays with water and place them in the school's freezer. Later that day (or the following day), have them retrieve the ice cubes from the school's freezer. Have each child place a paper towel on his or her desk and then distribute the ice cubes, one ice cube to each child. Give each child a thermometer. Tell the children to take the temperatures of their ice cubes by holding the tips of their thermometers against their ice cubes. Have the children observe their ice cubes as they melt on the paper towels. Tell the children to take the temperatures of the water on the paper towels after the ice cubes have melted. Ask the children to compare their temperatures taken before and after the melting of the ice cubes.

Measuring of weights, lengths, or capacities may also occur during early childhood science activities. Some of these may be suggested by the teacher (for example, how many ounces or milliliters does the shampoo bottle hold?) and some may occur naturally in the context of a project unit (for example, how many ounces of orange juice does each child need in order to get 60 calories of orange juice?). Remember that young children will measure non-standard and informal amounts before using standard measurements; thus, they may measure how many shampoo bottles fill a gallon milk jug before they measure how many ounces are held by a shampoo bottle. See Chapter 6 for more on measurement.

Predicting: Scientists are continually making predictions about the observations they will make and the experiments they will conduct. They learn from their predictions regardless of whether they are right or wrong because results of observations and experiments are always informative. Results help scientists to decide what to do next in the way of observations or experiments, and the same is true for the young child. Children as young as 3–4 years of age can be taught to make predictions. Some of these predictions are verbal while others are implied. In the following activity, predictions may be made with the body rather than with words.

Activity for Children 7.6

(Pendulum in the Classroom, Ages 3–5)[12]

For this activity, you need some type of sizable ball such as a tether ball and you need to hang it from the ceiling so that it rests about 2 inches from the floor. Also, you need approximately 6 square feet of space free where the ball is hung. After you secure the ball to the ceiling with an appropriate string or rope, test it. Make sure that it swings freely, without touching the floor, and that it stays attached to its fasteners on the ceiling. Allow some free play with the ball before you begin the activity. Most children will want to play with it. They may try to throw it. However, since it is attached to a rope, they will

(continued)

soon learn that it is easier to try to "pass" it to each other by holding the ball at a certain distance from the center and then letting go. They should become familiar with this feature of the hanging ball before they participate in the activity. If they ask you what its name is, tell them that it is a *pendulum*.

To begin the activity, place a doll or another sizeable object some place on the floor near the center of the pendulum's swinging path. Ask the children "Do you know where to put the doll so the pendulum will knock the doll over?" Most children will enjoy guessing where they should place the doll in order to make the path of the pendulum swing in such a way that the ball knocks over the doll. In science education terms, they are *predicting* where to stand in order to make the ball knock the doll over.

As children become successful at this task, you can make it more challenging by placing the doll further from the center of the pendulum's swinging path. You should also ask them where they can place the doll so that it cannot be knocked over by the pendulum (Kamii and DeVries, 1978, Chapter 8, pages 134–152).

Young children should be encouraged to predict before they experiment or observe results. The question "Will it sink or float?" requires the child to make a prediction. After the child places the object in water, the child will be able to observe whether or not this prediction was correct. The question "Do mealworms like apple?" requires a prediction followed by an observation. Young children should be asked to make predictions whenever they are about to experiment or make an observation. After they have observed, they should be asked to tell what happened and to try to explain why that particular result occurred. Jack Easley called this the Predict-Observe-Explain (POE) approach (in Duckworth, et al., 1990, Chapter 3). Questions that facilitate this approach are phrased along these lines: *What will happen if?* (This question requires a prediction) *What happened* (This question requires an observation) *Why do you think that happened?* (This question requires the child to think about possible explanations).

Activity for Children 7.7

(Sink and Float)

Give each child a container of water and a small collection of objects. Some should sink and others should float. For example, a collection of marbles, small pieces of wood, screws, nuts, bolts, and plastic objects would be good. Ask them to find out which objects sink and which objects float. When you distribute their collections of objects, distribute a simple chart with them. It should look roughly like this:

They can write the name of the object with invented spellings. If they can't write, they can draw a picture of the object (adjust the spaces in the chart to accommodate their drawings). Teach them to test each object one at a time. They should first make a prediction and record what they predict will happen under "I predict." Next, they should test the object in water and record the result under "What Happened?" Finally, in a couple of words, they should try to explain why the object sank or floated.

What it is	I Predict (Sink or Float?)	What Happened?	Why?

Communicating: People often have an image of scientists pursuing some esoteric question on their own in a lab coat. But scientists often work in teams and, even when they don't, they must communicate their findings with other scientists and with society at large. Communication involves reporting findings, debating explanations, and discussing ideas, as well as writing. Children's communication may include talking (Gallas, 1994 and Gallas, 1995), arguing and debating (Easley, in Duckworth et al, 1990, Chapter 3), writing, drawing, singing, and dancing (Gallas, 1994). It's useful for young children to keep a journal, even before they have achieved much skill at writing. They can include their drawings of the things they have observed and can tell their stories—about the experiences they associate with their science learning—through pictures and invented spellings. It's also important to remember that discussion of children's findings is as important as the actual hands-on exploration that they pursue; that is, young children learn best about science through hands-on exploration of science phenomena, but they must also carry out discussions with others about the things that they observe while exploring these phenomena. This discussion facilitates personal reflection about the hands-on experience. Teachers need to facilitate this discussion after the experimenting and observing has occurred.

We should also keep in mind the world of the young child (See Chapter 3 for more on this topic). Young children don't necessarily make a distinction between "science" and the rest of the world. Words like "science" are adult terms. The young child is curious about everything. Thus, if a child brings up a topic which seems unrelated to the topic that you, the teacher, thinks is the topic of discussion, it's *not* appropriate to tell him or her "We're not talking about that right now." For example, Gallas (1994) tells the story of a first grade child named John who wanted to write about rappers in his science journal because "it's so exciting!" (because rap is exciting). Gallas asked him "How does that make it science when it's something that's exciting?" and he replied

> 'cause sometimes they have wires hooked up like record players ... and that's electric.... 'cause like microphones are electric, and some microphones, they have wires hooked up to the ... radio ... [and] the pianos and stuff and they got it plugged in, and those are electric (p. 93).

In this case, the child was thinking about electricity when he wrote about rappers in his science journal. To a young child, whatever she or he is talking about may be related to the current classroom discussion. It's better to listen and try to see what sense a child is making of the discussion than to try to redirect his or her thoughts to the topic you have in mind. As we pointed out in Chapter 3, much more can be accomplished by listening.

Listening and observing are the primary means of assessing a child's understanding of science. A teacher can learn far more about what a particular child knows by listening to her or him (as Karen Gallas did in the conversation cited above about John's excitement for rappers) than she can learn from administering a test about the science curriculum. Likewise, a teacher can learn much by observing what a child chooses to do while engaged in the clay boats task described in *Activity for Children 7.4*. The most important thing a teacher can do after distributing hands-on science materials to children is to roam among the groups of children and observe what they *do* with the materials. You will, of course, need to supervise the children's behavior for purposes of safety and order, but your chief preoccupation should be to learn about the interests, questions and ideas of your children.

As students progress in their writing abilities, student journals will become another important way that you can assess your students' knowledge and understandings. Assessment can have a variety of purposes, but the most helpful types of assessments for teachers are those that provide them with insights about their students' ideas. Knowledge of your students' ideas will help you to decide what to do next during your instruction.

Processes Considered Developmentally Inappropriate for Young Children

There are other science processes that are not developmentally appropriate for early childhood; for example, conducting experiments by testing hypotheses and controlling variables. We will illustrate this with a specific teaching activity. A popular science activity to do with children and adults of all ages is to explore pendulums. We have already shared one example of a preschool activity with pendulums earlier in this chapter. Other activities include pendulum bowling (using pendulums to knock over inverted golf tees) and pendulums with salt (or sand) in cups that have small holes punched in the bottoms of the cups so they will leave a trail as they swing back and forth and around.

Another activity is to ask children to determine what makes pendulums swing faster or slower (as in *Activity for Future Teachers 7.4)*, but this is not developmentally appropriate for early childhood. Older children can go about this in a systematic way. For example, they may vary the length of the string while making sure that the weights attached to the pendulum string stay the same. In other words, they are controlling the variable of weight. Or, they may vary the weights of the objects that they attach to the pendulums while keeping the length of the string the same (controlling the variable of length). They won't vary both length and weight at the same time because that would confuse the interpretation of their results (If both things vary, then they don't know which factor made the difference). Young children don't typically go about their experiments in such systematic fashion. They often vary many things at once and come to a conclusion without worrying about isolating specific factors that might be responsible for the pendulum's speed.

We discussed the nature of the young child's thinking in depth in Chapter 3. Because of the young child's preoperational thinking, we recommend against using activities that require young children to test hypotheses or control variables. For the same reason, we do not recommend holding science fairs at the early childhood level. At least, we recommend against the type of science fair that requires children to test hypotheses.[13] Although some authors have developed approaches which claim that young children have succeeded at considering these variables, (1995) we have our doubts. However, we will not go into these doubts here since it would be more appropriate to do so in a research article. Suffice it to say that most early childhood and elementary science educators believe that the practice of requiring young children to test hypotheses and control variables is developmentally inappropriate. A teacher can

Activity for Future Teachers 7.4

Determining the Cause or Causes of a Pendulum's Speed

(Instructions for the professor)

Distribute the following materials to each cooperative learning group: steel washers of two or more sizes (obtain these from a hardware store), a ball of string, and a scissors. Make a pendulum yourself with a string about two feet long and a heavy washer. Introduce the activity by swinging your pendulum back and forth and talking about pendulums. Ask your students for examples of pendulums that they encounter in their everyday lives. Tell them that their task as group members is to work with the other members of their group to determine what makes a pendulum swing faster or slower. Don't give them any more guidance that this. For example, don't provide a working definition of "faster" or "slower." That should be left to them if they desire to develop one. Tell them to use the materials provided to answer this question. Also, tell them that they will need to report on their findings to the other members of the class and try to convince the rest of the class of their conclusions. Allow about 40 minutes for their experiments and allow at least 5 minutes per group for presenting their reports and conclusions to the class.

always structure a classroom activity so that each child has a container of plant seeds that are being cared for in specific ways. However, the question arises as to whether or not the young child fully understands the variables at play for these types of activities; that is, whether or not the structuring of the experiment came from the children or their teacher. If it came from the teacher, what are the odds that the child understands the purpose of structuring the experiment in that way?

Using Children's Ideas to Develop Instructional Activities: The Curricula of the 60s and 90s

A variety of curricula that respond to the questions of children have been developed for use at the elementary levels, beginning with kindergarten and ending at grade 6. The first set of these curricula were developed during the late 50s and the 60s. They were named *Elementary Science Study (ESS), Science Curriculum Improvement Study (SCIS)*, and *Science: A Process Approach (SAPA).* Each of these curriculum programs emphasized science processes to a greater or lesser degree. If we were to draw a continuum representing how much each of these programs emphasized science processes versus science content, it might look like this (see below).

In other words, the traditional textbook approach to teaching science emphasizes content but ignores science processes for the most part. SCIS reflects a roughly equal balance between science content and processes. SAPA and ESS are more concerned with processes than with content. The philosophy behind these programs is that children need to experience content through the context of hands-on exploration before they begin to commit specific content to memory. The constructivist curriculum of the 90s—for example, *Full Option Science Systems (FOSS), SCIS 3+, Insights, Delta Science Modules*, and *Science, Technology, and Children*—reflect the same balances as the 60s curricula. Because of their profound impact on ideas about teaching science to young children, we will deal with ESS and SCIS at this point in the text.

Elementary Science Study (ESS)

One of the most enjoyable (for the teacher) and engaging (for the child) aspects of *Elementary Science Study (ESS)* was its emphasis on play. The authors didn't call it play. They chose to call it "work." But it was "play" to the children who participated in the *ESS* instructional activities. The materials for the activities could be acquired in one of two ways: 1. The teachers could locate them by consulting the list of materials provided in the Teacher's Guides and gathering these materials on their own, or 2. The teacher or school could purchase a classroom kit for any particular instructional unit. Classroom kits provided enough of the necessary materials for each child in a classroom of 30 children to explore the materials on his or her own. Here's a quote about the theory underlying ESS, taken from *The ESS Reader* (Education Development Center, 1970).

> ... our approach should follow a ... strategy ... 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... (Education Development Center, 1970, p. 2).

Traditional Textbooks **SCIS** **SAPA** **ESS**

[---]

Content **Processes**

In other words, the child's personal interests and questions were pursued rather than the questions of the teacher or a set of required learning objectives or content standards. If the child learned about some of the content contained in the science content standards, that was an ancillary benefit of the activity—not a primary goal. In this type of classroom setting, "plastic sheets and tubes, metal rods, wooden balances, aquaria, leaves, copper wire, clay, mealworms, microscopes, and water are as natural as books and paper (Education Development Center, 1970, p. 3)." In other words, there must be "enough stuff" for children to explore (Hawkins, Frances, 1969, p. 51–61) and these personal explorations of the children cannot be replaced with academic talk or readings from a textbook. As *The ESS Reader* put it,

> pushing a lever or turning a crank, watching the fall of a column of water, seeing a yeast cell bud, [and] balancing on a swing are experiences which cannot be replaced by verbal formulations... (Education Development Center, 1970, p. 4).

To reiterate, no amount of talking or explaining science concepts to children can substitute for the actual hands-on exploration of science phenomena. The *ESS* curriculum was popular in elementary schools for about 25 years. However, the majority of elementary schools continued to use a textbook approach to teaching children about science, despite the research evidence that showed a hands-on approach works best. Eventually, during the 1990s, many of the ESS instructional units resurfaced as DELTA science modules. Similar units can be found in constructivist elementary science programs such as *INSIGHTS,* and *Science, Technology, and Children.*

Science Curriculum Improvement Study (SCIS)

Another popular elementary science curriculum that was begun during the 1960s was the Science Curriculum Improvement Study (SCIS). This was a comprehensive curriculum of hands-on instructional activities in the areas of physical science and life science (Karplus, 1964). The life science instructional units were especially well designed. While children can usually do experiments of some type when learning about physical science, life science activities more typically require observation on the part of the children; for example, observing the growth of plants on a daily basis by noting and recording the growth of each plant in millimeters or fractions of inches. Or, children may observe the activity of mealworms and find live examples of each stage of a mealworm's life cycle (See Activity for Future Teachers 7.1). The SCIS program went through several generations of improvements and publications and can still be found in classrooms today. The materials were provided in the form of classroom kits which provided enough materials for each child to explore on her or his own.

Hands-On, Minds-On Science Teaching: The Learning Cycle

One of the criticisms of ESS curricula that teachers often made was that they thought it looked too much like play. Of course, research has demonstrated since then that good science teaching *should* have a strong element of play in it. However, it's possible for children to enjoy the play experience and not learn that much from it. Consequently, a new term came to be used about science instruction during the 1990s. It was said that it's not enough for science learning to be *hands-on.* It also has to be *minds-on* (Duckworth, Easley, Hawkins, and Henriques, 1990). The structure of a good science lesson today must include at least both of these two elements: hands-on exploration, and "minds-on" reflection or discussion of the hands-on experiences. In this section, we will explain the meaning of these terms in more detail. The structure of the lesson was articulated in articles by David Hawkins (in *The ESS Reader,* Education Development Center, 1970) and Robert Karplus, the senior author of SCIS. Karplus called the structure of a science lesson *The Learning Cycle* (Karplus, 1964). For both of these authors, the first phase of a good lesson on science is the *hands-on* phase.

Phase 1: Hands-On "Exploration": It's important for you, the reader, to know that there are particular assumptions about learning behind this phase of a lesson. We will state these assumptions in the form of a premise (Premise #1).

> *Premise #1*: Children learn best through real-life experiences. A good math or science lesson includes hands-on experiences, involving the manipulation of materials or observation of living things. A good social studies lesson begins with an authentic situation. A good language arts lesson begins with the natural language of children. The first phase of a lesson organized as a learning cycle is called the *exploration* phase.

As a sort of abbreviation for this principle, we will use the term "hands-on activity." It is important to note, however, that we are not necessarily referring to cut-and-paste activities. For example, cutting, pasting, and coloring windmills is *not* "hands-on" science when the concept being developed is *the wind.* A "hands-on" exploration of wind currents might involve testing a student-constructed windmill outside to determine how fast or how slowly it spins as it is manipulated to face in different directions. On the other hand, cutting and pasting might be considered to be "hands-on" if the concepts being developed were *basic shapes.* In other words, for an experience to qualify as hands-on learning, it must relate to, and help a student to develop ideas about, the concept which is the focus of the lesson.

The selection of concepts to be developed during lessons should be based on the questions and thoughts children share during their natural interactions with peers and adults. For example, from Piagetian research on children's thinking, we already know about many of the ideas children have on specific topics of science. We know, for example, that young children are often confused about shadows and that they have many interesting ideas about them (See Chapter 2). Some children think shadows "come from" the night. Other children believe they come out of—and are attached to—the object casting the shadow. A good lesson on shadows will begin by having children explore their ideas further by casting shadows themselves, using a light source and some small objects.

When we help children to develop their *own* ideas about the world around them, to test them out and extend them, we are helping them to develop their *knowledge* of the world. This is far more important than trying to pass on our own knowledge—a knowledge most young children will be unable to truly understand at this stage.

Phase 2: Minds-On "Concept Development"[14]: As important as the hands-on activities *(exploration)* phase of the learning cycle is, research has shown that this is not enough. Hands-on experiences must be followed by *minds-on* experiences if true learning is to occur. This second phase has been labeled the *concept invention* phase of the learning cycle, because it is during this phase that the student reflects upon the hands-on experience in which he has participated and begins to come up with explanations for whatever has been observed. Usually, this reflection about the hands-on experience can be facilitated in one of two ways: 1. through questions posed by either the teacher or other students, and 2. through discussion and debate in a small group or with the whole class.

> *Premise 2*: Hands-on experiences alone do not necessarily foster learning. Students must be engaged in thoughtful reflection about these experiences in order for learning to result. Thoughtful reflection can be facilitated through discussion—with the whole class, in small groups, or individually, with another child or the teacher.

For science teaching in the primary grades, it is helpful for teachers to abandon the idea that they must pass on the "correct" explanations to their students. One problem with traditional science teaching has been that textbooks, in trying to express the *best* explanations for science topics, inadvertently oversimplify the complexity and debate that ordinarily are involved in scientific findings. As a consequence, students are given the mistaken impression that their own ideas about these topics don't matter. They infer that they need only to memorize the textbook's explanations for whatever phenomena they are studying, and this will make them knowledgeable. But the process of discovery in science is actually very controversial. It entails much debate and involves convincing others of one's opinions through the use of evidence obtained through careful observation and experiment. The ideas that guide scientists in this discovery process are hotly debated. If students don't experience this same type of debate about ideas *they* understand—and they best understand their *own* ideas—they will miss out on this major insight into how science works (Duckworth, et al., 1990, chapter 3).

In the concept invention phase of a lesson, the teacher must encourage discussion *and* debate! This is why so many constructivist educators say that correct answers should not be provided during this phase of a lesson. As Easley has pointed out, "firm belief in one's knowledge is a dangerous thing" because of "what it can do to discourage others and oneself from learning" (Duckworth, et al., 1990, p. 65). In other words, memorizing facts, formulas, or laws of science creates the illusion that you do not need to learn anything more about the topic in question. After all, the experts have already decided everything for you! Why would any student think further about his own ideas about everyday science phenomena when the experts had already explained them and the teacher has reinforced this by emphasizing the correct explanations in lectures and tests?

Discussion during this phase must encourage acceptance of *all* ideas and explanations. There will be plenty of time later for students to learn about the correct explanations. At this point, it is important that children learn two things: (1) how to articulate their own ideas about what they have experienced and observed (This is, after all, what scientists must also learn to do in order to communicate their findings to other scientists!) and (2) how to discuss and debate the ideas of others respectfully while at the same time requiring others to prove their ideas by providing evidence to support them. The second of these two learning goals for your students is especially challenging for primary teachers, since their students are just beginning to develop a logical form of reasoning (Piaget, 1926; 1928) and their discussions don't always appear to be logical.

Many teachers are troubled by the ideas that they should not give their students the correct explanations and that they should encourage debate among their students. "But won't they fight?" is a typical question. Rest assured, we are not advocating that you encourage your students to fight with each other. Teaching your students to respectfully listen to, and sometimes disagree with, the ideas of others is a basic social skill you should emphasize as part of your classroom management. Another question some teachers ask is: "Won't having the students disagree only make them more confused? They really *want* to know the right answers!" Easley's response to this question is especially instructive.

> In my experience, more challenging tasks can motivate more children and can help them develop their confidence, especially if they are supported by their teachers. What is puzzling to many teachers and future teachers... is that students working on such problems often disagree with their peers and are not able to resolve problems, and yet they are not discouraged. It is as though children, like scientists, know that they are better off if they can work out ideas themselves than if they are given the most authoritative answer they do not understand. (Duckworth, et al., 1990, p. 65)

It's not the *students* who become discouraged at not knowing the correct explanations—at least, not at the level of the primary grades. More likely, it's the *teachers*!

It is also interesting that students can work together, even when they disagree, and not be discouraged. One of the authors has made similar observations during his own nine years of experience as an elementary science teacher.

Some teachers are natural discussion leaders and need no particular guidance in how to make the most of the concept invention phase of a lesson. Others are less confident of their ability to teach students to respect all contributions to the class dialogue.

Depending on the grade level and intellectual maturity of the students, some teachers may prefer to intermix the exploration and concept invention phases of a lesson. Teachers who do this will interact individually with students, asking them to show the teacher what they are doing and to articulate their explanations for what they observe, while the teacher interacts with them *during* the hands-on activities. When this is done, any "challenging" the teacher may do is done one-on-one with each student.

Let's look at a couple of examples of how the development of a concept might be facilitated through classroom dialogue. The following discussion occurred in a grade 1–2 classroom (Gallas, 1994, p. 103–104).[15] The children are trying to answer the question "How did nature begin?"

> Robin: Nature was made... with dirt... and seeds... and the ... sun.
>
> Shelly: Well... how was the sun made? How was dirt made? ... How was oceans made?
>
> ...
>
> Brandy: I think... nature was made ... from... a seed ... under dirt, and then ... maybe ... roots started like coming, and then ... they dropped more seeds and then ... all that [the][16] plants came.
>
> Robin: Maybe.
>
> Donald: ... You know how there were plants way long ago? For dinosaurs to eat? Well maybe the leaves fell off, sometimes ... and they went ... deep into the ground, and you know the stems? The other part rotted ... and they started to grow nature.
>
> Brandy: ... but... how is the dirt ... made?

This type of discussion may, at first glance appear unproductive. But which would you, as a teacher of young children, prefer? Should your children memorize and repeat what you have said without understanding it, and then reproduce it when they take tests? Or, should they relate what they are learning and thinking about to the ideas which they already have and develop these ideas, through conversation, to the point where they mean something to them. Now, let's look at another classroom dialogue that occurred in the same classroom (Gallas, 1995, p. 33–34).

> Ellen: ... How did rice begin life? How did a plant begin? What made the seed?
>
> Molly: Maybe it started out with a kind of grass, like humans started out as animals and it got more like rice.
>
> John: Humans did start as animals.
>
> Shelly: Yeah, life started with grass 'cause rice is like a grass.
>
> Ellen: I know, 'cause grass seeds start turning like ricey.
>
> John: In the beginning, before people, we were monkeys.
>
> ...
>
> Shelly: You know how rice is a plant? And it's also a grass. So... the seed from the grass ... would drop off and some would blow away and then there would be more and more.

These children are taking turns making comments and the teacher deserves much credit for facilitating this type of dialogue in her classroom. The children are respectful of each others right to contribute. They are not completely influenced by each others ideas (Note, for example, John's repeated emphasis on the evolution of humans from animals). But that is to be expected of young children in the egocentric period of development. Despite this, there *is* mental processing of ideas happening for these children. That's the purpose of the concept development phase of the learning cycle—to encourage reflection and mental processing of the concept or concepts related to the lesson.

Phase 3: Application (Optional): This is the third phase of a learning cycle lesson, and it is optional.

The purpose of this phase is to help learners to mentally relate their experiences—and the ideas they have developed about them—to other experiences they have had, and to apply them to other situations. For example, during the first two phases of the learning cycle, children may have explored the sinking and floating of various objects in water and discussed what makes an object floatable. During the third phase of such a lesson, the teacher might ask students to think of situations in their personal experience outside of school where they noticed things that float; for example, boats on lakes, rivers, or the ocean, and toys in a bathtub or swimming pool.

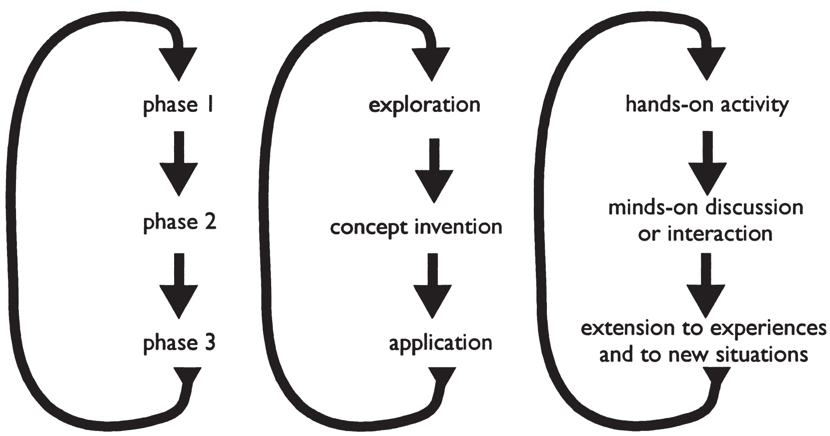
Questions that cause students to reflect on the nature of the academic discipline—in this case, science—are also appropriate during this phase. For example, for the lesson on which objects sink or float, the teacher might ask her children "When we say that something *floats,* what do we mean? What does that word—float—mean for each of us?" Asking students to clarify meanings introduces students to the nature of science because scientists must articulate operational definitions in order to communicate with each other.

> *Premise 3*: When students are challenged to apply their knowledge to personal experiences and new situations, their understanding is broadened because they see the connections between knowledge and everyday living.

Summary of the Learning Cycle: To summarize, the learning cycle includes three phases: *exploration (hands-on activity), concept invention (minds-on discussion or interaction),* and *application (extension to their own experiences and to new situations).* Figure 7.2 depicts the progression through these three phases. Note that the third phase, application, naturally "cycles back" to phase 1. In other words, after completing phase 3 of a lesson, a new lesson should be begun which carries out a new hands-on activity (exploration) suggested by the learning that occurred during phases 2 and phase 3 of the previous lesson.

Most lessons on physical science topics can be completed in a day because children can experiment with the materials, observe the results, and then discuss them. But some life science lessons take much longer. They must often extend over a period of days because plants take time to grow and pupa take time to hatch. The life cycle of a butterfly, from egg to adult, can take anywhere from a month to a year![17] However, there are some lessons for life science that can have a hands-on (exploration) phase as well as a minds-on (concept development) phase and be completed during the same period of the same day (taking a total of about 30–50 minutes). The following activity is an example of such a lesson. However, it would serve only as the "opening" lesson and would need to be followed up with several more sessions which cycle back and forth between the hands-on and minds-on phases.

The Learning Cycle



Created by Marie Louisell

Figure 7.2

An Example of a Lesson Following the Learning Cycle: We have chosen to describe this lesson in the format of a learning cycle lesson plan, so that you, the reader, can see how a learning cycle lesson plan is structured. (See Box 7.1).

Notice that this lesson plan included all three phases of a learning cycle lesson, even though we said that the *application* phase is optional. Box 7.2 provides a prototype of a lesson plan format for a learning cycle with explanations for each phase of the lesson.

Box 7.1

A Lesson Plan About the Life Cycle of a Mealworm

Materials Needed: Mealworms (obtain these from a pet shop), small plastic containers such as those used for take-out food (Be sure to punch holes in the tops so the mealworms can breathe), appropriate food such as oatmeal or breakfast cereal and a piece of apple or banana, and magnifying glasses.

Exploration *(Hands-On*): Give each pair of students a container of mealworms and two magnifying glasses. Invite them to explore the organisms by looking at them with their naked eyes as well as with the magnifiers. They can take the tops off of the containers, but they should make sure that none of the mealworms gets away from them. It's okay for the children to observe a particular mealworm on the table or desk for a while and then return it to its container.

Concept Development *(Minds-On):* While the children are observing the mealworms, ask them if they can see anything that looks like an "egg." Tell them the eggs are smaller and shaped like an egg (oval). When any child thinks s(he) has found one, check to observe with him or her. Allow him or her to show it to the other children so they know what to look for in their own containers. Next, tell the children that the worms eventually change to *pupas*. Pronounce this word for them and write it on the classroom board for them to see. Tell them that the pupas are not active. Tell the children that they may look as if they're dead but they are really in an "asleep" (dormant) stage so they can store up energy for the time when they will hatch into adults. Tell them that the pupa will become a beetle. Show them that you can poke a pupa gently with a fingernail or a pencil and it will momentarily behave as if it is awake, shaking its body for a short while before it goes back to its resting phase.

Application *(to Everyday Life):* In a discussion circle, ask the children what they learned about mealworms during this lesson. Allow children to share their observations and thoughts as fully as possible in the time you have allotted for this (5–10 minutes) Ask them if they know of any other insects that change from one form to another. Let them share any examples of which they are aware.

Box 7.2

Lesson Plan Format 2
for Lessons Following the Learning Cycle

Materials needed: as appropriate

Exploration: This is the ***hands-on*** phase of the lesson. For science, mathematics, art, or music, it should include a hands-on activity. For social studies, it should include an authentic learning activity or simulation; for language arts, a natural language activity. You can introduce your exploration activity with a task. For example, in a hands-on science activity, you might ask, "Can you do *X* ?" (e.g., "Can you get the bulb to light?") Or you might simply say, "See what you can do with these things!" (e.g., mirrors).

Concept Development: This is the *minds-on* phase of the lesson. True learning cannot occur unless the student reflects thoughtfully upon the experience that has been encountered in the exploration phase. Usually, this reflection is facilitated either through questions (posed by the teacher or other students) or through discussion and debate with a small group or the whole class. In this phase, the teacher should encourage discussion *and* debate. Children should be engaged in articulating their ideas about what they have experienced or observed. They should also be taught to discuss and debate the ideas of others respectfully.

Application: In this phase of the lesson, the learners are encouraged to mentally relate their experiences in the previous two phases of the lesson to other ideas and new situations. Applications to everyday life situations, such as those that occur with environmental impact considerations, are appropriate. Questions that cause students to reflect on the nature of a specific content or skill area are also helpful.

Content Standards for Science

Since the late 1980s and the first publication of content standards for mathematics by the National Council of Teachers of Mathematics (NCTM), there has been an active movement to develop content standards in all subject areas that are taught from preschool through grade 12. Content standards are statements about what students should know about a particular subject area by a specific grade level; for example, by the end of grade 2. There have been three sets of content standards for science education. The first published content standards for science education were *Benchmarks for Science Literacy* (1993). These dealt only with the content that should be taught at particular levels. Methods of teaching the content were not discussed. The second publication of science education standards, *National Science Education Standards* (1996), dealt with *how* to teach as well as with *what* to teach. Recently a third set of science education standards has been published, the *Next Generation Science Standards* (2013).

One example of a science content standard for early childhood is:

STANDARDS

By the end of the second grade, students should know that most living things need water, food, and air.

Source: Benchmarks for Science Literacy, p. 111

Further explanation of each standard is provided in explanatory material provided just before each content standard in the full edition of *Benchmarks for Science Literacy.*

States typically consult these national standards when developing their instructional goals for students at particular grade levels, and 26 states were involved in the creation of the *Next Generation Science Standards*. School districts typically adopt or revise the standards of their states when articulating instructional goals at the district level; however, most of the states involved in creating the *Next Generation Science Standards* are expected to adopt these standards as they are. Sometimes districts or states have developmentally appropriate goals (content standards) but they do not provide examples of appropriate activities for helping children to achieve these standards. In other cases, their goals may be developmentally inappropriate. For example, this happens when districts adopt standards that require students to use developmentally inappropriate thinking processes.

Positive Impacts of Content Standards On Science Teaching

There has been a mix of reactions to content standards for science. On the positive side, we can say that there has been more attention to science education at the elementary level since content standards emerged. Some states have chosen to require student assessments at the elementary levels that are based on science content standards. In these states, school districts have adopted constructivist science curriculum programs such as those discussed in a previous section of this chapter. Teachers have allotted specific daily times in their students' schedules for the teaching of science. Also, there has been more discussion of specific science content standards among teachers as far as which ones are most difficult or easy for the students to learn and which ones are developmentally inappropriate. The processes used in developing the *Next Generation Science Standards* and also the NCTM *Principles and Standards* were especially thorough; for example, the *Next Generation Science Standards* involved educators from 26 states and invited public comment. The NCTM accepted public comment for a period of two years before publishing them in their final form.

Negative Impacts of Content Standards On Science Teaching

On the other hand, there have been some negative impacts of the science content standards on student learning of science. These include the following.

Standardized Testing Focuses on Content at the Expense of Process: Although there is no reason why states *must* use standardized tests to assess student achievement of content standards, most states have chosen to do so. It's been well established in the field of tests and measurement that it's difficult to assess higher-level thinking, including science processes, through traditional standardized tests. The decision by the overwhelming majority of states to rely on standardized testing has resulted in a skewed focus on lower-level content at the expense of assessing higher-level thinking and science processes. Because the tests have stressed lower-level content learning, districts and teachers have also stressed these things. In other words, they are "teaching to the test" instead of teaching the most important science goals. This trivializes science education and also reduces the amount of engaging science activities that children are involved in. Since research has also documented a relationship between play and cognitive development (Rathbone, 1971), standardized testing has also had a negative affect on the child's development in general.

When Content Standards Are Developmentally Inappropriate: In some cases, the stated goals are developmentally inappropriate. For example, suppose your school district had the following standard as one of its goals for science knowledge to be achieved during first grade.

> **The child will be able to explain that the earth revolves around the sun and the moon revolves around the earth.**

Now, think about the children discussed in Chapter 2 who believed that the moon follows them. Is there any way that this goal could be considered developmentally appropriate for children who believe that the moon follows them? The answer is obviously "No!" When the child has developed further intellectually, this goal will be appropriate, but it should not be required in early childhood curriculum. There are many creative ways to help children to develop this understanding—for example, making a classroom-size model of the solar system (or at least the sun, the earth, and the moon). But even the most creative approaches to teaching this goal will be a mismatch to the child's development during early childhood, at least for most children.

For cooperative discussion: When district or state content standards don't relate to the questions and ideas of young children, what should you, as a teacher, do?

Summing up, it's important to be aware of the standards that have been articulated for the levels of children whom you teach. However, it's also important that you, as a teacher of young children, make thoughtful judgments about the developmental appropriateness of these goals for the young children whom you teach, based upon your knowledge and experience with these and similar children.

Now, let's look at another standard—one taken from the Next Generation Science Standards published in 2013.

> **Science investigations begin with a question. (Understandings About the Nature of Science, K–2).**

It sounds good, doesn't it? Who could argue with the idea that science investigation begins with a question? But, although the idea is correct (science investigations *do* begin with a question), it's not necessarily developmentally appropriate. Why not? Because six year old children are more likely to view what they do in classrooms as *play*—not "investigation." And the child may not distinguish between "science" and other activities during her or his day.

How Science Processes interact with Content: If you think back to the continuum we provided earlier in the chapter that arranged science textbooks and constructivist elementary science programs according to how much content versus process that they emphasized, you will realize that there are several ways to deal with the interaction of science content and science processes. Textbooks focus on science content and largely exclude the higher-level thinking processes of science. Some of the hands-on science curricula—ESS and SAPA, in particular—deal with content as more or less an incidental by-product of the playful hands-on experience. But the young child is curious by nature and she will be thinking about science as she plays with the materials during a hands-on activity. She may not realize that the things she is contemplating are "science," but she will be thinking about these things nonetheless. For example, when a young child repeatedly constructs and reconstructs a clay boat, she is thinking about the various factors that affect whether a boat sinks or floats; for instance, the height of the sides of the boat (to keep water from going in over the top and sinking the boat), the thickness of the clay on the sides and bottom of the boat (It will sink if it is too thick, but it may develop leaks if it is too thin), etc. In middle school or high school, she may learn that density and specific gravity are the primary factors affecting the floatability of an object. However, she is thinking about these things as a young child while making clay boats even though she is not yet aware of these science vocabulary words or their meaning. She hasn't fully developed these concepts yet, nor has she learned the names for them, but she is thinking about them when she constructs and reconstructs her clay boat.

Endnotes

1 As mentioned in Chapter 2, many of these ideas were either stated or implied in Jack Easley's chapter (Duckworth, Easley, Hawkins, and Henriques, 1990).

2 Brackets inserted by the author.

3 Our youngest daughter, Sarah, asked us this question when she was about that age.

4 Eleanor Duckworth, Jack Easley, David Hawkins, and Androula Henriques, *Science Education: A Minds-On Approach For the Elementary Years.* Hillsdale: Lawrence Erlbaum Associates. 1990, pages 87–93.

5 A newer version of *Bloom's Taxonomy* was published by Raths et al (2002) but we prefer to use the original version for our purposes here.

[6] Note: For this activity, course instructors should schedule brief class discussions for each class session or pose questions for students on Blackboard or a similar online class discussion board.
[7] Adapted from *Elementary Science Methods: A Constructivist Approach,* by David Jerner Martin (2009), p. 77–78.
[8] National Council of Teachers of Mathematics, Principles and Standards (2000)
[9] It must be oil-based—not water-based—clay. Water-based clay falls apart in water.
[10] The author first learned of this activity by reading the Teacher's Guide for *ESS Clay Boats.*
[11] Children can be provided with digital thermometers, which are easier to read, until they are ready to learn how to read thermometers with scale markings.
[12] I first learned about using pendulums with preschoolers when I read *Physical Knowledge in Preschool Education: Implications of Piaget's Theory* by Constance Kamii and Rheta Devries
[13] Another type of science fair simply requires that children learn more about a particular topic and communicate about it. This is a bit like the "project work" and "topic work" that we discuss in Chapter 11, except for the fact that it is specifically focused on the science aspect of a topic.
[14] Karplus (1964) chose to call this phase "concept invention" because children must "invent" concepts on their own if they are to truly transform this knowledge into something that they can personally understand. However, we recognize that not all children will accomplish this goal, so we use the more relative term, *concept development.*
[15] Many parts of this excerpt were deleted in order to make our presentation of it more succinct. Ellipses indicate omitted comments.
[16] Our brackets.
[17] http://www.thebutterflysite.com/life-cycle.shtml

References

American Association for the Advancement of Science (AAAS) Project 2061 (1993). *Benchmarks for Science Literacy*. New York: Oxford University Press.

Duckworth, Eleanor (1987). *The Having of Wonderful Ideas: and Other Essays On Teaching and Learning.* New York: Teachers College Press.

Duckworth, Eleanor, Easley, Jack, Hawkins, David, and Henriques, Androula (1990). *Science education: A minds-on approach for the elementary years.* Hillsdale: Lawrence Erlbaum.

Easley, Jack (1990). "Stressing Dialogic Skill" in *Science education: A minds-on approach for the elementary years,* by Duckworth et al (op. cit.). Hillsdale: Lawrence Erlbaum.

Education Development Corporation (1969). *ESS Clay Boats.* New York: McGraw-Hill: Webster Division.

______. (1970). *The ESS Reader.* Newton, Massachusetts: EDC.

Gallas, Karen (1994). *The Languages of Learning: How Children Talk, Write, Dance, Draw, and Sing Their Understanding of the World.* New York: Teachers College Press.

______. (1995). *Talking Their Way Into Science: Hearing Children's Questions and Theories, Responding with Curricula.* New York: Teachers College Press.

Hawkins, David (1970). "Messing About in Science" in *The ESS Reader.* Education Development Center. Newton, Massachusetts, p. 37–44.

Hawkins, Frances (1969). *The Logic of Action.* New York: Pantheon.

Kamii, Constance, and Rheta DeVries (1978). *Physical Knowledge in Preschool Education: Implications of Piaget's Theory.* Englewood Cliffs, NJ: Prentice-Hall.

Karplus, Robert (1964), "The Science Curriculum Improvement Study" in *Journal of Research in Science Teaching.* Volume 2, Issue 4 (December, 1964).

Louisell, Robert and Jorge Descamps (2001). *Developing A Teaching Style–2e.* Prospect Heights, IL: Waveland Press.

Martin, David Jerner (2009). *Elementary Science Methods: A Constructivist Approach,* Belmont, CA: Wadsworth.

Metz, K. E. (1995). "Reassessment of Developmental Constraints in Science Instruction." *Review of Educational Research.* Summer, Volume 65, Number 2.

National Council of Teachers of Mathematics (2000). *Principles and Standards.* Reston, VA: NCTM.

National Research Council (1997). *National Science Education Standards*. Washington, DC: National Academy Press.

National Research Council (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Rathbone, Charles (1971). "The Plowden Report: Two Excerpts" in *Open Education: The Informal Classroom*. New York: Citation.

Raths, James. "Improving Instruction" in *Theory Into Practice*, Volume 41, Issue 4 (Fall, 2002).

The Butterfly Site.com. http://www.thebutterflysite.com/life-cycle.shtml

Index

About the Authors

Robert Louisell holds a doctorate in elementary and early childhood education from University of Illinois and is Professor Emeritus at St. Cloud State University. He has seven years of teaching experience in public schools at the early childhood level. He has taught in early childhood education programs at St. Ambrose University and University of Texas, El Paso, and in the elementary education program at St. Cloud State University. He is also the co-author of *Developing a Teaching Style* (Harper-Collins, 1992, Waveland Press, 2001).

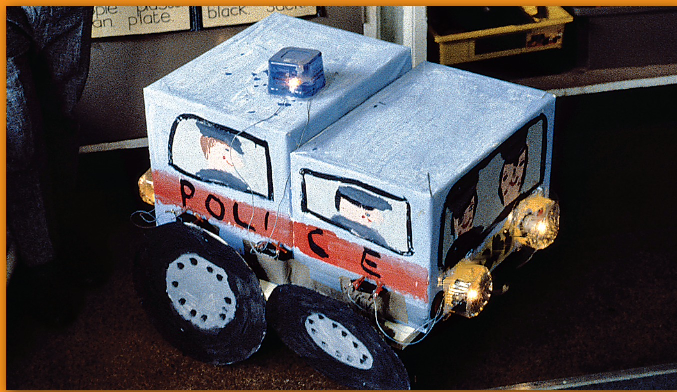
Stephen Hornstein is a professor in the College of Education at St. Cloud State University. His special interests include authentic mathematics curriculum and assessments during the early childhood and elementary years. He is also a proponent of whole mathematics and he has served as president of the Whole Language Umbrella and as a math coach at Tse'ii'ahi Community School in Standing Rock, New Mexico. His international experience includes consulting in Nigeria.

Peter Frost has taught education courses at Bath College of Higher Education in Bath, England and at William Jewel College in Kansas. He also has several years of teaching experience in primary schools. He was CEO of the National Primary Trust, Director of the Gifted and Talented Academy, and Policy Adviser for Government of England during 2005–8.

I DO, AND I UNDERSTAND

Helping Young Children Discover Science and Mathematics

"A merit of his liberalized Piagetian approach is to help educators to take a subject's perspective about children as learners. These analyses of Dr. Louisell's yield wise advice on educational strategies, which might help to refine interventions in elementary science education."
— Juan Pascual-Leone



Facsimile of a Police Car Built By Children

(About science activities)
"If we provide hands-on situations for children—for example, exploring density by testing out which objects sink and float or learning about electricity by experimenting with batteries, bulbs, and wires—they will reflect on the science phenomena that they observe and develop their own ideas about them."


Paintings by 1st Grade Children After Trip to Zoo

(About constructivism)
"When we help children to develop their *own* ideas about the world around them... we are helping them develop *their* knowledge of the world. This is far more important than trying to pass on our own knowledge — a knowledge most young children will be unable to understand at this stage."

"Previous texts on the subject … neglected … grade levels one through three. This book … comprehensively deals with preschool/kindergarten *and* grades 1–3 and it contains over a hundred tested early childhood activities for mathematics and science."

Robert Louisell holds a doctorate in elementary and early childhood education from University of Illinois and is Professor Emeritus at St. Cloud State University. He has seven years of teaching experience in public schools at the early childhood level. He has taught in early childhood education programs at St. Ambrose University and University of Texas, El Paso, and in the elementary education program at St. Cloud State University. He is also the co-author of *Developing a Teaching Style* (Harper-Collins, 1992, Waveland Press, 2001).

ISBN 13: 978-1-934478-36-3
ISBN 10: 1-934478-36-9
90000
9 781934 478363

Constructivist Press
www.constructivistpress.com

$ 75.00