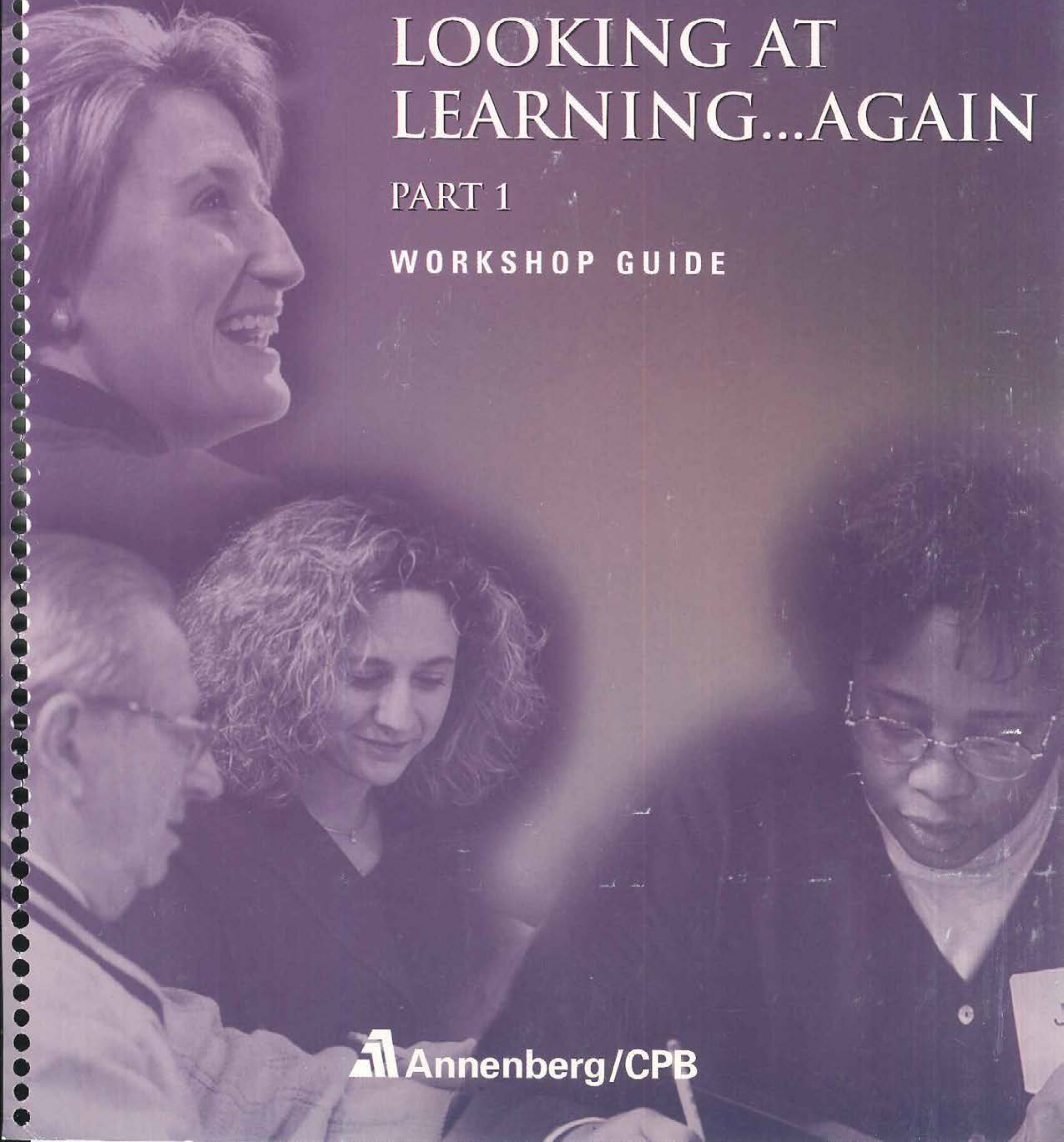
PROFESSIONAL DEVELOPMENT WORKSHOP

LOOKING AT LEARNING...AGAIN

PART 1

WORKSHOP GUIDE



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Professional Development Workshop Guide

Looking at Learning . . . Again

Part 1

An eight-part professional development workshop for K-12 math and science teachers

Produced by Harvard University and the Smithsonian Institution

Looking at Learning...Again, Part 1

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About the Workshops

Series Overview

Ever since the first time teachers tried to influence students, there has been controversy surrounding the methods they used. In the years since Socrates first created and honed his famous method, hundreds of educators have developed theories about learning and teaching. Among these, there are many areas of convergence, as well as a few instances of contention, but all have in common a focus on how children learn and how best to create situations in which learning can take place. For today's teachers the challenge becomes "What are these theories really telling us? What do we do with these seemingly complicated and overlapping arguments?" And equally compelling is how the questions surrounding these ideas are viewed by professionals against the background of their own personal beliefs about teaching and learning.

To this end, **Looking at Learning . . . Again** invites seven leading educators to share the origin, structure, research base, and applicability of their arguments for creating the most efficient and productive learning environments for students in our elementary and secondary mathematics and science classes.

Teachers are the backbone of the educational system. Like educational theorists, they continually develop new ideas and insights, question current practices, and strive to keep education a living and changing organism. Both teachers and theorists bring to the table a wealth of experience that has shaped their ideas on what teaching and learning should be. But all too often, teachers and theorists work in isolation, and new educational theories do not always find their way into the classroom. This workshop series provides an opportunity for practitioners to explore, discuss, critique, and ultimately implement the ideas and strategies of seven leading educational theorists—an important step toward making the teaching of mathematics and science more effective.

About the Workshops

Workshop Descriptions

Workshop 1: The Many Faces of Learning

Reflect on your own personal beliefs about learning, and discover why it is important for teachers to examine and reexamine the learning process.

Workshop 2: Intellectual Development

Share ways to elicit, accept, and build on students' ideas, and discover the connection between student ideas and intellectual development.

Workshop 3: Conceptual Thinking

Consider how students learn by assimilating new concepts into their already existing frameworks.

Workshop 4: Inquiry

Explore why inquiry learning is essential in mathematics and science, and develop several strategies for inquiry-based teaching.

Workshop 5: Idea-Making

Investigate how facilitating the construction of students' own mathematical ideas has a positive effect on learning.

Workshop 6: The Mind's Intelligences

Review Gardner's theory of multiple intelligences and learn how to create learning environments that support the full spectrum of students' intelligences and abilities.

Workshop 7: Design, Construction, and Technology

Examine the effect of technology on learning when students design and develop tools to support their own inquiries.

Workshop 8: Intellectual Development

Analyze differences in curricula, textbooks, and teaching practices around the world, and discuss how these differences affect student learning in mathematics and science.

About the Workshops

Video Clip Descriptions

WORKSHOP 1

In the Dark
Richard and Karen, grade 8, discuss their ideas of light and vision.

Looking at Learning . . . Again
Guest educators explain why it is important to continually examine learning.

WORKSHOP 2

Batteries and Bulbs
Kris Newton's 9th grade class at the Cambridge Rindge & Latin School (Cambridge, MA) begins a unit on batteries and bulbs.

Tea for 40 (T-440)
A group of teachers who have worked with Eleanor Duckworth for more than 15 years meets once a month to share activities and discuss their own learning.

Mission Hill School (Boston, MA)
Eleanor Duckworth conducts a workshop in which teachers, parents, and staff examine their own understandings about a particular phenomenon.

WORKSHOP 3

Rocks and Minerals
Tom Vaughn's 9th grade earth science class at Arlington High School (Arlington, MA) makes concept maps on atomic structure as they begin a unit on rocks and minerals.

Plane Geometry
Colleen Schultz's 8th grade algebra class at the Vestal Middle School (Vestal, NY) makes concept maps to review a unit on plane geometry before a test.

WORKSHOP 4

Wetlands
Erien Gordon's 5th grade class in Methuen, MA, observes the wetlands behind their school in order to come up with questions for an investigation.

Pendulums
Margarita Manso-Rosa's students in a 5-8th grade bilingual (Spanish) class in Cambridge, MA, share their results of a pendulum investigation and ask each other questions about what they've learned.

Paper Trusses
Nancy Cianchetta's 8th grade students in Everett, MA move from disinterest to involvement when they are presented with a paper truss challenge.

WORKSHOP 5

Mental Addition
Meredith Livings's 2nd grade class at the South Shades Crest School (Hoover, AL) engages in "mind mathematics" as the students solve double digit addition problems in their heads.

Mental Multiplication
Sherry Parrish's 4th grade students at the South Shades Crest School describe and defend their strategies for solving double digit multiplication problems in their heads.

WORKSHOP 6

Ross School (E. Hampton, NY)
See a number of multiple intelligence strategies in practice:

Nichelle Wilson's 6th grade art class—"The Golden Mean"

Rick Faloon's 10th grade math class—Probability

Debra McCall's 7th grade history class—Roman architecture

David Purvis's 5th grade science class—Stars, Sun, and constellations

WORKSHOP 7

Girl Scouts Clubhouse
At a computer clubhouse run by the Patriot Trail Girl Scouts (Boston, MA), girls ages 8 to 11 design projects on the computer, under the guidance of teenage mentors.

Robots
In Ronnie Ranere's K-1 class at the Bronx New School (Bronx, NY), students use robots to figure out distance on number lines.

Crickets
In Mark Hardy's 4th and 5th-grade class at the Bronx New School, students use "crickets" to collect temperature data before and after a walk.

WORKSHOP 8

Third International Mathematics and Science Study (TIMSS)
A high school math class in Japan works on a challenging geometry problem.

Round Table
A group of teachers, administrators, and parents discuss how the TIMSS results reflect cultural and societal values and share their own ideas about what we, as a society, can do to improve our education system for our children.

About the Contributors

MICHAEL R. COHEN, Ph.D. (Content Advisor)

Dr. Michael Cohen is a Professor of Science and Environmental Education at Indiana University-Purdue University at Indianapolis. Dr. Cohen began his teaching career as a Junior High School science teacher, where he discovered that his students were his best teachers. For 30 years, he has used those early lessons as the basis of his research on children's science concepts. His studies have been used in science curricula, teacher education projects, and two textbook series he co-authored: *Scott-Foresman Science* and *Discover Science.*

REBECCA CORWIN, Ed.D. (Content Advisor)

Dr. Rebecca Corwin taught 5th grade for ten years. She is currently Professor of Education at Lesley College, and works with her graduate students in an elementary school in Boston in order to bring their practical and theoretical knowledge together as they learn to be teachers. Dr. Corwin has written a number of books for teachers, including the *Used Numbers* series about statistics and data analysis.

ANNA GOODSON (Interviewer)

Anna Goodson is the Director of Educational Services at Alabama Public Television where she works with teachers, administrators, and organizations to provide educational programming for school districts statewide. She teaches teachers how to use television as an instructional tool. Ms. Goodson has planned and facilitated educational programs at the Birmingham Zoo (Birmingham, AL), and has also taught gifted and talented students at both the elementary and middle school levels.

KALPANA GUTTMAN (Interviewer)

Kalpana Guttman holds a Master's of Education in both Elementary Education and Computers in Education. She has taught at the preschool and elementary levels for sixteen years. She has also worked at the Arnold Arboretum (Jamaica Plain, MA) where she worked with teachers on developing a constructivist approach to science teaching, and assisted them in incorporating technology into their classrooms. Ms. Guttman currently teaches 5th grade in Newton, MA.

RICHARD KONICEK, Ed.D. (Content Advisor)

Dr. Richard Konicek has been involved in science education for 38 years. He has conducted research, taught junior high school, and worked as a K-12 science curriculum coordinator. Dr. Konicek is now a Professor of Science Education at the University of Massachusetts in Amherst, where he teaches elementary science methods and research courses focused on the application of research to teaching.

SUSAN MATTSON, Ph.D. (Content Advisor, Interviewer)

Dr. Mattson received a B.A. in Biology from the University of California at Berkeley, followed by a Master's in Biology and Ph.D. in Science Education from Florida State University. In addition to teaching science methods courses for early childhood and elementary education majors, her experiences include curriculum development in the sciences and professional development for teachers. Dr. Mattson has recently returned to the classroom to teach high school biology.

JAYNE OGATA (Host)

Jayne Ogata has worked for the past ten years as a performing artist and educator in the Boston area. She has also toured with Shakespeare & Company's education program, bringing theater performances and workshops to schools throughout New England and in New York City. Ms. Ogata recently earned her Master's of Education in Learning and Teaching from the Harvard Graduate School of Education. She continues to participate in creating quality educational programming for the classroom, workshops, stage, and broadcast media.

MAURICE PAGE (Interviewer)

Maurice Page has been teaching mathematics for 30 years. He has taught elementary, middle, and high school students, and currently teaches at the high school level at the Cambridge Rindge & Latin School (Cambridge, MA). Mr. Page also teaches mathematics methods courses to education majors at the Harvard Graduate School of Education and is a consultant for the science and mathematics teaching course at the MIT Teacher Education Program.

PHILIP SADLER, Ed.D. (Content Advisor)

Dr. Philip Sadler has a joint appointment as the Assistant Professor of Science Education at the Harvard Graduate School of Education, and the Director of the Science Education Department at the Harvard-Smithsonian Center for Astrophysics. Dr. Sadler is also the founder of Learning Technologies, Inc., a company creating science learning tools used each year by over 3 million students in 18 countries.

LISA SCHNEIER (Content Advisor, Interviewer)

Lisa Schneier has been a teacher and program developer at Boston English High School. She has also worked at the Massachusetts Corporation for Educational Telecommunications (MCET) as a curriculum developer. She has been a student and colleague of Eleanor Duckworth since 1983, and has used this work in her teaching and in research that documents 9th grade students learning poetry.

JAY SUGARMAN, Ed.D. (Host, Content Advisor)

Dr. Jay Sugarman holds a Master's of Science of Teaching in Elementary Education, and an Ed. D. in Curriculum and Instruction. He has been an elementary school teacher for 25 years, and currently teaches 4th grade at the Runkle School (Brookline, MA). Dr. Sugarman also teaches a number of education courses to undergraduate students at Simmons College.

TEREZ WALDOCH, Ph.D. (Interviewer)

Dr. Terez Waldoch is currently Assistant Principal at the Wildwood Elementary School in Amherst, MA. During her 25-year teaching career, she worked as a science curriculum coordinator, co-chaired a curriculum overview committee, and presented science workshops for teachers. In 1993, Dr. Waldoch was recognized with the Presidential Award for Excellence in Science Teaching in the Commonwealth of Massachusetts.

YVONNE WATSON (Host)

Yvonne Watson has been an elementary school teacher with the Boston School Department for 19 years. Actively involved in Boston's school change efforts, Ms. Watson serves as a member of the Instructional Leadership Team at the Manning School. She is also a lead teacher working as Boston Curriculum Standards Facilitator for the Office of Curriculum and Instruction. Ms. Watson has a passion for creating new ways to help children think critically and satisfy their natural curiosity about the world while developing basic skills.

JEFFREY WINOKUR (Host)

Jeffrey Winokur is an early childhood and elementary science specialist at Wheelock College (Boston, MA), where he teaches both undergraduate and graduate-level courses in science teaching. Mr. Winokur has worked with a number of Massachusetts school districts on the development of their elementary science programs, and has also consulted with early childhood programs throughout New England to provide teacher workshops on science for young children.

Workshop Components

Day of each workshop

Site Investigation: GETTING READY
30 minutes of discussion and activity to prepare you for the workshop video

Workshop Video
60 minutes of video with guest interviews, classroom footage, teacher panels, and more

Site Investigation: GOING FURTHER
30 minutes of discussion and activity to wrap up the workshop video

Between workshops

Homework Assignment
an exercise or activity that ties into the previous workshop or prepares you for the next one

Reading Assignment
an introduction to the ideas of the guest who will be featured in the upcoming workshop

Ongoing Activity
Moon Journal: an ongoing Moon observation activity to help you reflect on your own learning process

Web site
a place to go for additional activities, resources, and discussion

www.learner.org/channel/workshops/lala

Channel-Talk
an opportunity to communicate with other workshop participants via email

To subscribe to Channel-Talk (the workshop email discussion list)

Send an email message to: channel-talk-request@learner.org
The message should read: subscribe channel-talk <Your Name>
For example: subscribe channel-talk Amanda Cho
Be sure to remove any signature files before sending your message.

Helpful Hints

Successful Site Investigations

Included in the materials for each workshop you will find detailed instructions for the content of your Getting Ready and your Going Further Site Investigations. The following hints are intended to help you and your colleagues get the most out of these pre- and post-video discussions.

Designate a facilitator.

Each week, one person should be responsible for facilitating the Site Investigations (or you might select two people—one to facilitate Getting Ready, the other to facilitate Going Further). The facilitator does not need to be the Site Leader, nor does it need to be the same person(s) each week. In fact, we recommend that participants rotate the role of facilitator on a weekly basis.

Review the Site Investigations.

Be sure to read over the Getting Ready and Going Further sections of your materials before arriving at each workshop. The Site Investigations will be the most productive if you and your colleagues come to the workshops prepared for the discussions.

Bring the necessary materials.

A few of the Site Investigations require group brainstorming or list making. In these instances, it will be useful to have markers and chart paper or newsprint. The facilitator should be responsible for bringing these materials, when necessary. **You will need these materials for Workshop 1.**

Keep an eye on the time.

Thirty minutes go by very quickly, and it is easy to lose track of the time. We have suggested the amount of time that you should spend on each question or activity. While these times are merely a guideline, you should keep an eye on the clock so that you are able to get through everything before the workshop video begins. In fact, you may want to set a small alarm clock or kitchen timer before you begin the Getting Ready Site Investigation to ensure that you won't miss the beginning of the video. (Sites that are watching the workshops on videotape will have more flexibility if their Site Investigations run longer than expected.)

Record you discussions.

We recommend that someone take notes during each Site Investigation, or even better, that you make an audiotape recording of the discussions each week. These notes and/or audiotape can serve as "make-up" materials in case anyone misses a workshop.

Share your discussions on the Internet.

The Site Investigations are merely a starting point. We encourage you to continue your discussions with participants from other sites on the discussion area of the Web site and on Channel-Talk, the workshop email discussion list.

Ongoing Activity—Moon Journal

Overview

The behavior of the Moon is a phenomenon that we have all experienced during the entirety of our lives, but very few of us have spent time thoughtfully observing its behavior. Think about it for a moment . . . when was the last time you saw the Moon? What did it look like? If you went outside right now, would you be able to see the Moon? Where in the sky would you look to find it? What would it look like? No matter how much you already know about the Moon's behavior, there is always something new to learn!

Throughout this workshop series, you are encouraged to learn about the Moon by keeping a Moon Journal. This means simply going outside several nights a week to observe the Moon, recording your observations on a drawing, and reflecting on your observations in a journal. Your recordings or data will become a path for you to follow as you look for patterns in the Moon's behavior and build your knowledge both about the Moon, and also about your own learning process.

In Workshop 1, you and your colleagues will be asked to develop a Moon Chart to display the group's collective knowledge about the Moon. The chart will grow and change over time as you gather new knowledge through your observations of the Moon. Several times throughout the series you will have an opportunity to discuss your findings with your colleagues, but you are encouraged to update the Moon Chart weekly, even when no specific Moon discussions are planned.

Experiencing the process of learning new content is a useful way to reflect on your own personal beliefs about learning. As you progress through the Moon Journal activity, think not only about what you are learning, but how you are learning. Whether you teach first graders or high school seniors, math or science, keeping a Moon Journal will provide a shared experience that will enable you and your colleagues to examine your own learning processes, and will lend insight into your beliefs about how your students, and others, learn.

Ongoing Activity—Moon Journal

Instructions

Materials: drawing paper and pencil, directional compass, notebook

1. Choose a location convenient to your home or work with as clear a view as possible of the southern sky. (Use a compass to locate south. If you do not have a compass, call the direction of the setting Sun west, and then approximate south.) When facing south, you should be able to look east (to your left) and west (to your right) without any major obstacles blocking your view.

2. You should make all of your Moon observations from the same location. To help you find this location each time you make an observation, identify the location by pushing a stick or stone into the ground or making a scratch or chalk mark on a paved surface.

3. Make an **Observation Sheet.** On a plain sheet of paper, draw the horizon you see while standing in your location and looking south. Place south in the center of your drawing, and include anything that falls into your field of view (buildings, trees, hills, etc.) These landmarks will provide you with reference points when you draw the Moon's position.

4. Choose a specific time to make your observations and make all your Moon observations within the same 30-minute period every evening. If you're not sure when to make your observations, refer to an almanac to find the time of moonrise and moonset. You also may be able to find this information on a calendar. Moon observations can be started any time during the sequence of the Moon's phases. If you cannot observe every evening, we recommend that you observe at least four times per week.

5. For each observation, draw the Moon on your Observation Sheet, recording both its position in the sky as well as its apparent shape. Write the date next to each drawing of the Moon.

6. After you have observed the Moon, make an entry in a notebook, or **Moon Journal.** Record the date, time, apparent shape of the Moon, and anything interesting or unusual you observe about the Moon or the sky. You should also take some time to write a few reflections, such as what you saw, what you think about what you saw, what questions you have, or what you've learned. We will suggest some Moon Journal questions in each workshop, but you should not feel obliged to answer the questions we provide. Write about what moves you, and remember to consider your own learning process.

7. Bring your Observation Sheet and Moon Journal with you to each workshop and discuss your findings with your colleagues, when time allows. Also, record your new ideas and questions on the Moon Chart at each workshop (see Going Further, page 18).

Ongoing Activity—Moon Journal

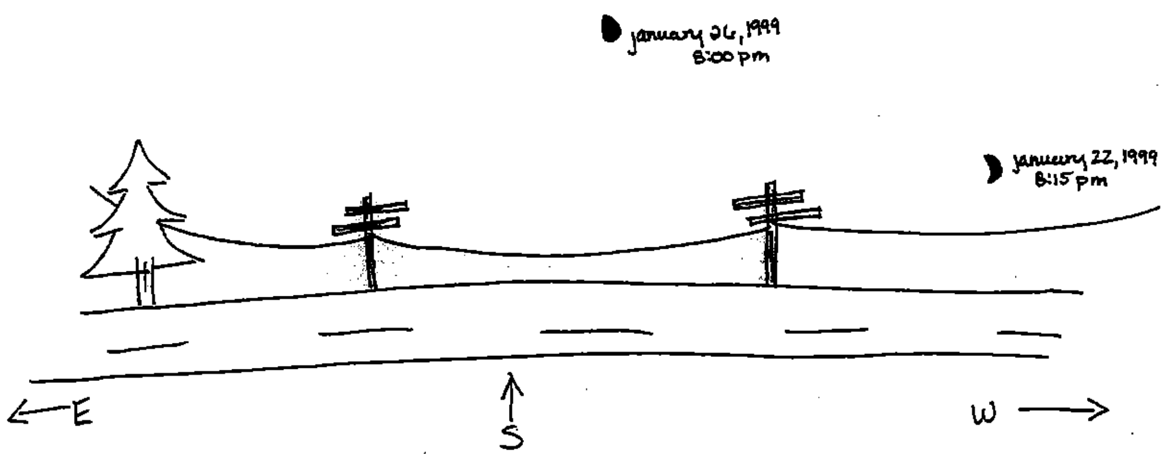
Sample Moon Journal Entry

January 22, 1999, 8:15pm

Tonight when I went outside during my observation time I noticed the Moon in the western portion of the sky. This was the shape of the Moon at this time:

Sometimes when I go outside at lunchtime I notice the Moon. I wonder if there is a time when the Moon is only visible during the day and not at night???

Sample Moon Observation Sheet



Adapted from:

Coyle, H.P., Gregory, B., Luzader, W.M., Sadler, P.M., & Shapiro, I.I. (1993). *Project STAR: The universe in your hands.* Kendall/Hunt Publishing Co.: Dubuque, Iowa.

Brandou, B. (1997). Backyard astronomy: Observing Moon phases. *Science and Children,* 34(8), 18-21, 48.

Education Development Center, Inc. (1968). *Where is the Moon? Teacher's Guide.* McGraw-Hill Book Company: St. Louis, MO.

Workshop 1: The Many Faces of Learning

In this introductory workshop, you will meet the guest educators who will be featured in the series and hear why they think it is important to continually examine the learning process. You will also have an opportunity to reflect on your own personal beliefs about learning, and see clips of classrooms that will be presented in more detail in later workshops.

SELF CHECK

This icon indicates a self check activity. These activities are designed to help you reflect practically on the theories presented by the workshop guests. Specifically, they will enable you to investigate your own beliefs and behaviors, and sometimes those of your students. We hope that these activities will help you to further examine your ideas about how people learn and how these ideas might influence your teaching.

Workshop 1 timeline

GETTING READY

30 minutes

15 minutes—Learning a Task

In pairs, select one of the following tasks that you both know how to do:

balance a checkbook	cook a turkey	fix a leaky faucet
use a graphing calculator	determine report card grades	potty train a toddler
prepare an income tax return	change a flat tire	install computer software

Discuss with your partner how you learned to do the task. Did you both learn it the same way? How might others learn it? Could anyone learn it? How would you teach someone else to do it?

15 minutes—Learning Chart

The activity you just did should have generated some thoughts about learning. Discuss as a group. On a large piece of newsprint or chart paper, start two lists:

Our **Ideas** about Learning   Our **Questions** about Learning

These lists represent what you know and what you want to know about learning right now. As you progress through the workshop series, your ideas and questions about learning will grow and change, and you should add to the lists accordingly.

Select a volunteer to bring the Learning Chart to each workshop.

WATCH THE WORKSHOP VIDEO

60 minutes

1. What questions about how we learn does this video clip raise for you?
   clip - Girl in the Dark (Karen) from Minds of Our Own.

2. If you put a camera in your classroom, what would you notice?
   Does what you notice reflect your ideas about learning?
   Share one observation with your colleagues.

Workshop 1 timeline

GOING FURTHER

30 minutes

15 minutes—Helping Karen "see"

Think of an experience or activity that you could provide for Karen that would convince her that you need light to see. Share your ideas with your colleagues.

15 minutes—Moon Chart

Discuss what you know and what you want to know about the behavior of the Moon. On a large piece of newsprint or chart paper, start two lists:

Our **Ideas** about the Moon   Our **Questions** about the Moon

You should add to these lists as you observe the Moon throughout the workshop series.

Select a volunteer to bring the Moon Chart to each workshop.

For next time

HOMEWORK ASSIGNMENT

Make a list of the all the different ways one could seat students in a classroom (e.g. in rows, in a semicircle, in groups of four, etc.). Select three different seating arrangements from your list and write about what that arrangement suggests about the teacher's teaching style. The student's learning style? The activity in which the students are engaged?

READING ASSIGNMENT

In preparation for Workshop 2, please read *The Virtues of Not Knowing* by Eleanor Duckworth. (All readings are included in the Appendix.)

You may also want to read Duckworth's article *The Having of Wonderful Ideas*. See Related Resources (page 57) for the citation.

MOON JOURNAL

We encourage you to get started on your Moon observations right away so that you can collect as much data as possible over the course of this workshop series. Instructions for the Moon Journal activity can be found on page 14.

Here's a possible way to get started on your first Moon Journal entry:

Recall the Moon Chart you made with your colleagues at the start of Workshop 1 (See Getting Ready, page 17). Select one of the questions that were posed during the discussion, and respond to it. Do you have any initial ideas about the answer to your question?

Workshop 2: Intellectual Development

In this workshop, you will explore the power of the mind and consider the notion that every child can learn everything. Eleanor Duckworth will discuss the importance of teaching for a deep and lasting understanding, and will explain why it is important to give students time to work through their own ideas and experience confusion in order to achieve such understanding.

FEATURING

ELEANOR DUCKWORTH

Professor of Education at the Harvard Graduate School of Education and a former student, colleague, and translator of Jean Piaget, Eleanor Duckworth grounds her work in Piaget's theories of the nature and development of intelligence. Her own interest, however, is in teaching and in the experience of teachers and learners of all ages, both in and out of schools. She has worked on curriculum development, teacher education, and program evaluation in the United States, Switzerland, Africa, and her native Canada. She is the author of *The Having of Wonderful Ideas* and *Teacher to Teacher: Learning from Each Other*.

Workshop 2 timeline

GETTING READY

30 minutes

30 minutes—Going to the Movies

How many different ways can four children sit in adjacent seats at a movie theater?

You may know a formula for solving the problem, but take a few moments to explore the different arrangements themselves. You might want to use four small objects to represent the children, or you could use a symbolic notation with pen and paper.

When you think you have identified all the arrangements, convince a partner that there are no more possibilities, and explain how you know for sure that you have found them all.

Your homework will be to ask two of your students to do this problem. Select two students that you think will approach the problem differently. Take a moment now to decide which students you will ask and to predict how they will solve the problem.

! **Remember to update the Moon and Learning Charts.**

WATCH THE WORKSHOP VIDEO

60 minutes

1. Think of a unit you are currently teaching. How might you construct this lesson so that students can "enter" the subject matter in more than one way?

2. Describe the characteristics in a classroom in which students are comfortable struggling with their ideas. Brainstorm strategies you might use to create such an atmosphere.

GOING FURTHER

30 minutes

10 minutes—Moon Discussion

By now, you should have begun your Moon observations and Moon Journal. Discuss your progress. Is the process working for you? Have you had any problems? Remember to add new ideas and questions to the Moon Chart.

20 minutes—Finding a Balance

Letting students "take the lead" in the classroom and develop their own understandings may be great for their learning, but is it so great for the teacher? In most school districts, teachers are held accountable by mandatory local and state tests. How can you "let kids go" so they can learn from their own ideas, and at the same time make sure that they know the content—the facts—to succeed on the mandatory tests? How do you find the balance? What are some things you can do?

For next time

HOMEWORK ASSIGNMENT

Recall the "Going to the Movies" problem that you did at the start of Workshop 2 (see Getting Ready, page 21). Select two students whom you think will approach the problem differently, and predict how they will solve the problem. Then present the problem to the students. You may need to ask some probing questions, such as:

How did you find your answer?

How do you know that there are no more possibilities?

Is there any other way you could have solved the problem?

After working with both students, compare their approaches to your original predictions. What impressed you most about their problem solving methods? What surprised you? What can you do in your teaching that will enable you to continue to learn these kinds of things about your students?

READING ASSIGNMENT

In preparation for Workshop 3, please read "How Do We Learn Our Lesson?" by Joseph Novak. (All readings are included in the Appendix.)

MOON JOURNAL

Here are some questions to consider as you continue to observe the Moon:

Does the appearance of the Moon change over time?
Does its size change?
Its shape?
Its color?

Suggested activity

Measuring the Moon's Diameter

When making your Moon observations, take a ruler with you. Hold the ruler at arm's length from your body and measure the diameter of the Moon in centimeters. Record your finding and try it again the following night. Does the diameter of the Moon change every night? Can the diameter of the Moon really be measured in centimeters with a ruler?

For more accuracy, you can measure the Moon's diameter using a Cross Staff. Here's how.

BUILDING A CROSS STAFF

MATERIALS:

Cross Staff template (p. 24)
Paste or glue
Cardstock
Meter stick
Scissors

INSTRUCTIONS

1. Adhere the Cross Staff template to a piece of cardstock and cut along the solid lines. Be sure to cut out the notch at the top of the template and the rectangular slot in the center.
2. Push a meter stick through the rectangular slot and make sure that the card can move freely up and down the length of the meter stick.

USING A CROSS STAFF

1. On a night when the Moon is at or near full, hold the meter stick with the zero end touching your cheek and the meter stick pointing towards the Moon.
2. Slide the card along the meter stick until the Moon just fills the notch. (It may be helpful to close one eye while looking at the Moon through the notch.)
3. Note the distance along the meter stick between the card and the end closest to your eye.
4. You can now calculate the diameter of the Moon using the following ratio:

$$\frac{\text{width of notch}}{\text{distance from card to eye}} = \frac{\text{diameter of Moon}}{\text{distance to Moon}}$$

Use the distance 400,000 km as the distance from the Earth to the Moon. (The accepted value is 384,401 km.)

EXTENSIONS

Often the Moon looks "bigger" when it is near the horizon. How could you use a Cross Staff to check whether or not this is a true phenomenon?

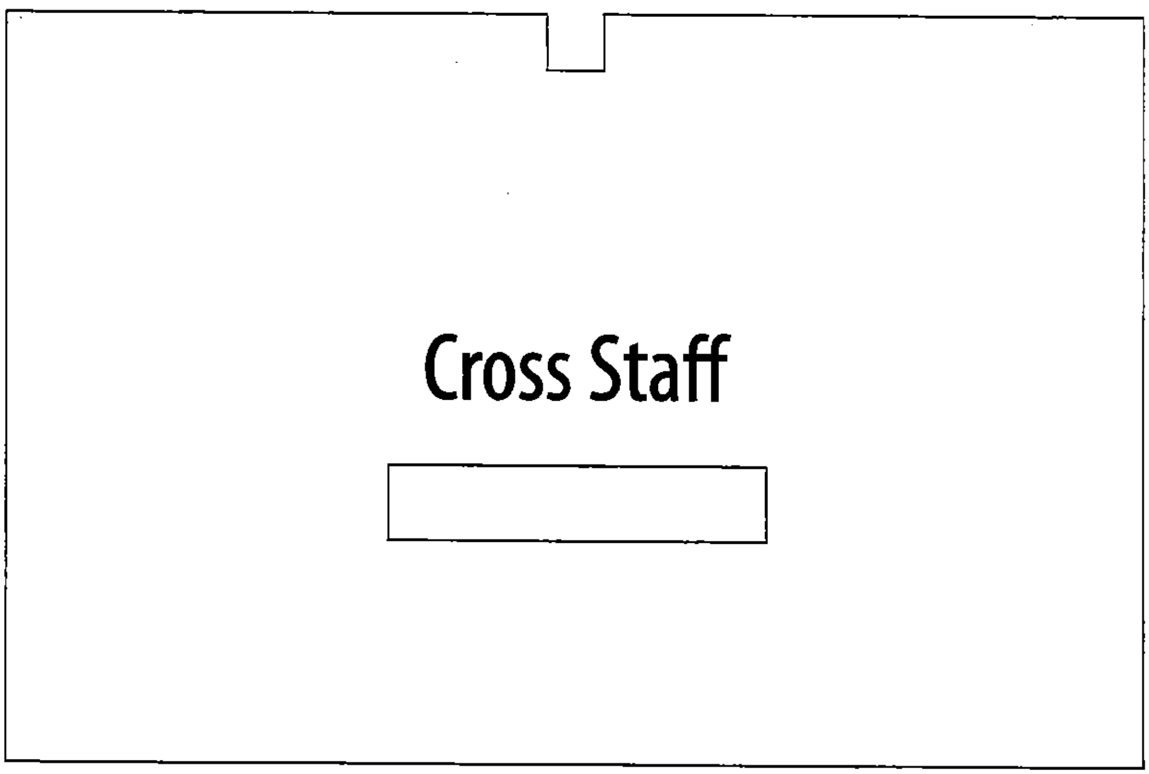
A Cross Staff can be used to determine the dimensions of other objects once their distance from the observer is known.

Adapted from:

Hall, J. (1994). Calculating the Moon's diameter. In N.B. Ball, H.P. Coyle, & I.I. Shapiro (Eds.) *A teacher resource to enhance astronomy education: Project SPICA.* Kendall/Hunt Publishing Co.: Dubuque, Iowa.

Wong, O.K. (1987, October). "How wide is the Moon?" *The Science Teacher.*

CROSS STAFF TEMPLATE



Workshop 3: Conceptual Thinking

This workshop will focus on concept maps as tools for helping students learn. Joseph Novak will explain how students learn by assimilating new concepts into their already existing frameworks, and will take a teacher step-by-step through the design and process of concept mapping. You will see concept maps being used in a variety of different ways in mathematics and science lessons, and will even have an opportunity to make some concept maps of your own.

FEATURING

JOSEPH D. NOVAK

Professor of Biological Science and Science Education recently retired from Cornell University, Joseph Novak is one of the seminal investigators in the research in children's ideas in science. He is the author of *Learning How to Learn* and a developer of the concept mapping formalism. His latest book, *Learning, Creating, and Using Knowledge,* was published in 1998. *Teaching Science for Understanding,* co-authored with Mintzes and Wandersee, was also published in 1998.

Workshop 3 timeline

GETTING READY
30 minutes

20 minutes— Moon Discussion

Examine the Moon Chart that you made in Workshop 1. In your observations of the Moon thus far, have you gathered any data that supports or challenges the information on the Moon Ideas list? Share and discuss your information, and update the chart.

Have you or your colleagues developed any new questions that you can add to the Moon Questions list? Consider where these questions came from. What, specifically, inspired the questions?

Now that you have thought about your own questions, think about your students. Where do you think they get their questions?

10 minutes— Concept Map Discussion

Have you ever used concept mapping in your classroom? How have you used concept maps (i.e., for what purpose)? What kinds of things have your students mapped?

Remember to update the Moon and Learning Charts.

WATCH THE WORKSHOP VIDEO
60 minutes

1. What strategies do you use to determine your students' understanding? How might you use concept maps for this purpose?
2. Make a concept map of a topic you are going to teach next week.

GOING FURTHER
30 minutes

30 minutes—Making Concept Maps

In pairs, have one person construct a concept map about **teaching** while the other person makes one about **learning**. After you have made the two concept maps, compare them. What are the similarities? The differences? Did the word "teach" appear in the **learning** concept map? Did "learn" appear in the **teaching** map? How do you believe teaching and learning should be connected?

Save your concept map—you will need it again in Workshop 8.

Note: You can assess your students' prior knowledge of a particular topic by having them make concept maps before you prepare and introduce the lesson on that topic. You might have them make concept maps again at the end of the lesson, and compare the before and after maps to see what they've learned.

For next time

HOMEWORK ASSIGNMENT

Using the materials of your choice, make two pendulums (e.g., hand-held, taped to a table edge, free-standing) with the following specifications:

Pendulum 1: a period of 15 swings in 10 seconds
Pendulum 2: a period of 30 swings in 30 seconds

Please bring your pendulums with you to Workshop 4.

READING ASSIGNMENT

In preparation for Workshop 4, please read "Assessing 'Imperfect' Conceptions" by Hubert Dyasi. (All readings are included in the Appendix.)

MOON JOURNAL

Here are more suggestions for your Moon Journal:

Does the Moon's position change over time?

If you want to record the Moon's exact position in the sky in your journal, what information do you need?

Where do you predict the Moon will be positioned in the sky tomorrow night during your regular observing time? One week from now?

Suggested activity

Measuring the Elevation of the Moon

One piece of information helpful in describing the Moon's position is its height in angles (*angular height*) above the horizon. The horizon is the line along which the sky and land—or sea—appear to meet. You can determine the Moon's height above the horizon if you know the angle between the line from your eyes to the Moon and the line from your eyes to a point on the horizon directly below the Moon.

MEASURING WITH FISTS

You can estimate the Moon's angular height by simply using your hands. Stretch one arm out straight and make a fist with the hand on your outstretched arm. From the horizon to the highest point in the sky is one quarter of a circle or 90 degrees. If you measure with fists, putting one fist on top of the other, nine fists will about equal this angle—one (adult) fist is roughly the same as 10 degrees.

To measure the angular height of the Moon at any given time, stretch one arm out straight and make a fist with the hand on your outstretched arm. Close one eye and adjust your sight so the outstretched fist is aligned with the horizon. Make a fist with your other hand and stack it on top of the first. Continue stacking your fists, one on top of the other, until the Moon appears to be covered by one of the fists. The number of fists you stacked indicates the angular height of the Moon. For example, if you counted six fists, the angular height of the Moon above the horizon would be approximately 60 degrees.

MEASURING WITH A CLINOMETER

A clinometer is a tool that can help you to measure the angular height of the Moon more accurately than with your fists.

MATERIALS:

Protractor template (p. 30)
Cardstock
Paste or glue
Drinking straw
Clear tape
Scissors
30 cm fishing line or kite string
Metal washer or weight with hole
Tack or pin

BUILDING A CLINOMETER

1. Adhere the protractor template to a piece of cardstock and cut along the dotted lines.
2. Center the straw lengthwise along the edge of the template directly above the straight side of the protractor. Secure it in this position with tape.
3. At the point where the protractor's center line (0 degrees) meets with the line that runs parallel to the straw, use a tack or pin to make a hole.
4. Thread one end of the fishing line or kite string through the hole so that approximately 2 cm extends out the back side of the protractor. Secure this portion of string to the back side of the protractor.
5. Tie the metal washer to the opposite end of the fishing line or kite string. The string and washer should swing freely along the front side of the protractor.

USING A CLINOMETER

1. Position the Clinometer straw-side up so the straw is parallel to the ground and the string hangs parallel to the 0 degree marking on the protractor.
2. Look through the straw and adjust the position of the Clinometer until you sight the horizon directly below the Moon (while keeping the straw parallel to the ground).
3. While looking through the straw, tip the entire Clinometer upward until you can sight the Moon through the straw.
4. As you move the Clinometer, the string moves along the protractor. By noting the position of the string along the protractor, you can determine how many degrees you are tipping the Clinometer to sight the Moon. This measurement is the angular height of the Moon.

EXTENSIONS

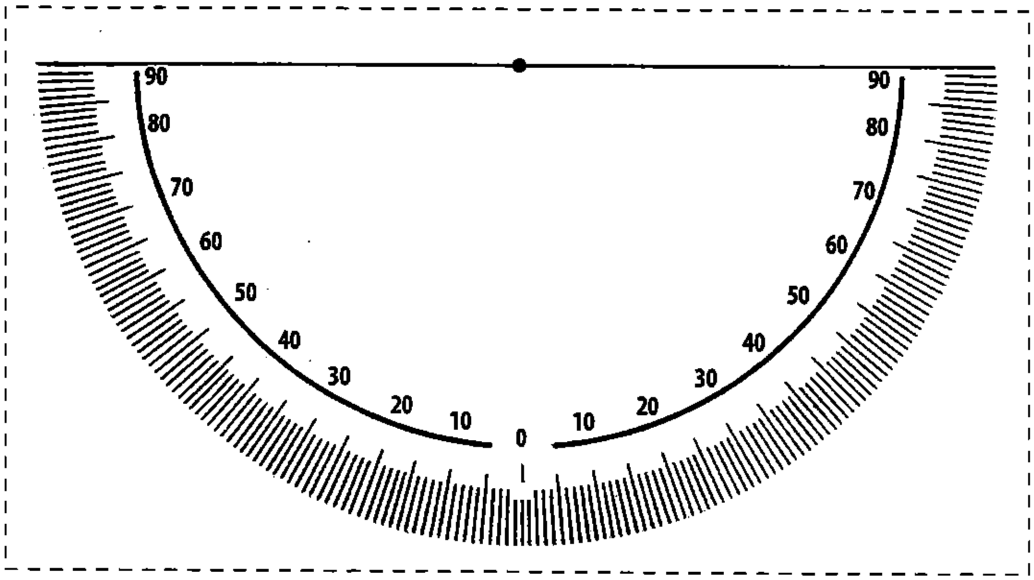
To measure the height of an object that makes a right angle with the land, such as a tree or a building, sight the top of the object through your clinometer and walk towards the object until the clinometer measures 45 degrees. By mentally tracking from your observation point to the base of the object to the top of the object and back to your observation point, you will make an isosceles triangle. Given that two sides of an isosceles triangle are equal, you can determine that the distance from the observation point to the object itself will be equal to the height of the object.

Adapted from:

Coyle, H.P., Gregory, B., Luzader, W.M., Sadler, P.M., & Shapiro, I.I. (1993). *Project STAR: The universe in your hands.* Kendall/Hunt Publishing Co.: Dubuque, Iowa.

Education Development Center, Inc. (1968). *Where is the moon?* Webster Division, McGraw-Hill Book Co.: New York.

PROTRACTOR TEMPLATE



Workshop 4: Inquiry

In this workshop, Hubert Dyasi will discuss inquiry-based learning in science and explain why it is essential in all subjects. You will see several classrooms where inquiry learning is taking place and explore various inquiry strategies you can use in your own classroom.

FEATURING

HUBERT DYASI

Professor of Science Education at the City College (City University of New York), Hubert Dyasi is Director of the Workshop Center, a science teacher development institution at the College. He has been a Co-Principal Investigator in the New York State Systemic Initiative on K-8 mathematics, science, and technology education, and has served as a member of the working group on teaching standards for the National Science Education Standards (National Research Council). Dyasi is one of the authors of *Designing Professional Development for Teachers of Science and Mathematics.*

Workshop 4 timeline

GETTING READY

30 minutes

30 minutes—Pendulum Discussion

For this workshop, you were asked to make two pendulums. In small groups, demonstrate your pendulums, then discuss the following:

What process did you use to design your pendulums?
What (if any) problems did you encounter?

What is the most significant thing you learned about pendulums?
Why is it significant?

What are three questions that you still have about pendulums?

Do you consider the pendulum activity to be an inquiry activity?
What is your definition of inquiry?

WATCH THE WORKSHOP VIDEO

60 minutes

1. Think of a unit you currently teach. What phenomenon in your students' every day environment might you use as a means for starting an inquiry in this unit? Share your ideas with your colleagues.

2. Choose one coponent of the inquiry process. How might you integrate this component in a unit you currently teach?

GOING FURTHER

30 minutes

15 minutes—Paper Trusses

In the workshop video, you saw Nancy's students involved in a paper truss activity. How might you take this activity further? What other challenges could you present to extend this inquiry activity in a math or science classroom?

Note: The paper truss activity comes from Coyle, H.P., J.L. Hines, K.J. Rasmussen, and P.M. Sadler, editors, *Science in Action,* Dubuque: Kendall/Hunt Publishing Company, 1999. (In Press)

15 minutes—Revisit Learning Charts

By now, you've had a chance to think about your own learning and your students' learning in many different ways. Think back on some of the avenues we've used to explore learning—the "Going to the Movies" problem, pendulums, your Moon Journal, concept mapping . . . Have your ideas about learning changed at all? Do you have more thoughts? More questions?

Take some time now to add your new ideas and questions to the Learning Chart.

For next time

HOMEWORK ASSIGNMENT

Select one of your students and write a brief narrative from his/her perspective answering the question, "How do I learn science/mathematics in this class?" Some questions to guide your narrative might include:

What do I do? What is my job in this class?
What does my teacher do? What is his/her job?
What is the job of the other students in the class?

Now interview the student, asking the same questions. How did his/her actual answers compare to the responses you anticipated in your narrative? Were there similarities? Differences? What do these similarities/differences mean in terms of your teaching? In terms of your student's learning?

If you have time, interview a second student. Not all students will respond the same way, and it's sometimes useful to compare answers.

Please bring one of the following games with you to Workshop 5: Checkers, Chinese Checkers, Battleship, Mancala, Yahtzee, Sorry, Parcheesi, Cribbage, deck of cards (Rummy, Hearts, Poker, Go Fish, etc.).

READING ASSIGNMENT

In preparation for Workshop 5, please read "Reform in Primary Mathematics Education: A Constructivist View " by Kamii, C., Lewis, B.A., and Sally Jones. (All readings are included in the Appendix.)

MOON JOURNAL

Here is something interesting to think about:

Observe the position of the Sun with respect to the Moon in the sky. Does the angle between the Sun and the Moon increase, decrease, or stay the same over your observation period?

Suggested activity

Sun, Earth and Moon Angles

One way to chart the Moon's behavior is to chart its position with respect to the Sun and the Earth. Specifically, you can measure the angle between the Moon and the Sun, with the Earth as the vertex of the angle.

At a time when both the Moon and the Sun are visible, measure the angle between the Moon and the Sun from your observing location. Each time you measure and record the angle, also observe and record the shape (phase) of the Moon, and notice whether the lit or unlit portion of the Moon is nearest the Sun.

CAUTION: Never look directly at the Sun.

ESTIMATING ANGLES WITH FISTS

Just as you can use fists to measure the elevation of the Moon (see page 28), you can do the same to measure the angle between the Sun and the Moon. Make a fist with each of your hands and hold them out in front of you at arm's length. Count how many fists make up the distance between the Moon and the Sun.

MEASURING ANGLES WITH A PROTRACTOR

MATERIALS:

Clinometer (see pages 28–30).

INSTRUCTIONS

1. Position your clinometer with the protractor numbers face-up.
2. Point one end of the straw to the Moon.
3. Slide the string along the top of the protractor until it is aligned with the direction of the Sun.
4. Use the numbers along the side of the protractor to calculate the angle between the Sun and the Moon.

QUESTIONS

1. Is the lit or unlit part of the Moon facing the direction of the Sun?
2. Which direction are the "horns" of a crescent facing with respect to the Sun? Does this change as the angle between the Moon and the Sun changes?
3. Do you notice a pattern between the Moon-Sun angle and the phases of the Moon?

Workshop 5: Idea-Making

This workshop will focus on student idea-making in mathematics. Constance Kamii will explain how you can adapt your teaching to help students construct their own mathematical ideas. You will see video of students engaged in "mind mathematics" articulate and defend their strategies to classmates, and you will consider the value of using games to facilitate mathematics teaching and learning.

FEATURING

CONSTANCE KAMII

Professor of Early Childhood Education at the University of Alabama at Birmingham, Constance Kamii studied under Jean Piaget for a dozen years, first as a postdoctoral research fellow and later as an adjunct professor at the University of Geneva. She developed a preschool curriculum based on Piaget's theory, especially in science, mathematics, and the sociomoral realm, and is now developing an elementary math program based on his theory. Kamii is the author of *Young Children Reinvent Arithmetic; Young Children Continue to Reinvent Arithmetic, 2nd Grade;* and *Young Children Continue to Reinvent Arithmetic, 3rd Grade.*

Workshop 5 timeline

GETTING READY

30 minutes

15 minutes—Game Play

You were asked to bring in some common household board, card, and dice games. Divide into small groups and select a game to play. While you are playing, think about what (if any) math skills students would need to play the game successfully. What are some math concepts (if any) that students might learn from playing the game?

15 minutes—Game Discussion

Rejoin the large group and discuss the following: How does playing games compare to more traditional math exercises such as worksheets, flash cards, or problem sets? What are the advantages of games? Disadvantages?

WATCH THE WORKSHOP VIDEO

60 minutes

1. What does a student learn by having to explain his or her mathematical thinking to the class? Take into consideration cognitive, content and social/emotional aspects.
2. How does Sherry create an atmosphere in which the students can invent their own solutions? Generate a list of techniques that she uses to do this. How does each technique support children's learning?

GOING FURTHER

30 minutes

30 minutes—Tricks and Procedures

When asked in her interview what headline she would give to a newspaper article about her approach to learning, Dr. Kamii said, "Traditional math education harms children's development of numerical thinking." She went on to explain her belief that teaching children to memorize rules and algorithms such as carrying, borrowing, and long division prevents them from inventing their own solutions to problems and forces them to give up their own thinking.

Do you agree that teaching algorithms and procedures, tricks and equations, has a negative effect on student learning? What are the advantages of algorithms from a teacher's perspective? From a learner's perspective? What are the disadvantages? How would your school district react to Dr. Kamii's statement?

For next time

HOMEWORK ASSIGNMENT

How comfortable are you with letting students develop and pursue their own inquiry? To test your comfort level, try this—during the next week, incorporate into a lesson some sort of class discussion in which students can talk about their opinions or rationales for solving something. During this class discussion, see how many times you can let the comments pass from student to student without an intervening question or comment from you. It's not easy!

How many students were able to speak consecutively before you spoke? When did you intervene? Why? What sort of discussion was happening when you jumped in? What could you do next time to let the discussion go further on its own?

READING ASSIGNMENT

In preparation for Workshop 6, please read "Developing the Spectrum of Human Intelligence" by Howard Gardner. (All readings are included in the Appendix.)

MOON JOURNAL

You might want to reflect on the following in your Moon Journal:

Why does the Moon appear to shine?

Why does the Moon appear to change its shape?

Is there an order to the Moon's phases? If so, can you determine the order?

Suggested activity

Modeling the Phases of the Moon

To do this activity effectively, the room must be as dark as possible. Darken the room by closing the blinds and covering all window and door cracks with black paper or cloth and tape.

MATERIALS:

Lamp
Extension cord
Clear light bulb (75 watts or more)
3-inch Styrofoam ball
Craft stick

INSTRUCTIONS

1. Make a "handle" for your Styrofoam ball by carefully pushing a craft stick into the ball. Hold the handle so the Moon ball is positioned upright.
2. You will be part of a model that portrays the phases of the Moon. In the model, your head will represent the Earth, the Styrofoam ball will represent the Moon, and the lamp will represent the Sun.
3. Place the lamp in the center of the room and turn it on. Turn off the room lights and then stand approximately two arm-lengths away from the lamp.
4. Hold the Moon ball directly in front of the lamp and at arm's length from your body, pointing upwards approximately 45 degrees. Notice that as you hold the Moon ball in front of your body and turn around, sometimes part of the ball is lit, and sometimes the whole hemisphere facing you is lit.
5. Keep turning until you can see a thin crescent lit up on the Moon ball.
6. Continue moving in the same direction until the Moon ball looks like a half-lit circle.
7. Continue moving in the same direction until the ball looks completely lit.

QUESTIONS

1. Is the brightest side of the Moon facing towards or away from the Sun?
2. For the Moon to appear "fuller," how does it have to change its position relative to the Sun?
3. When the Moon is full, is it on the side of the Earth that's closest to the Sun, or the side that's farthest away from the Sun?
4. Are the phases of the Moon the same in the northern and southern hemispheres?

EXTENSIONS

On a sunny day when the Moon is visible, go outside with your Styrofoam Moon ball. Stand facing the Moon, holding out your Moon ball at arm's length "covering" the Moon in the sky. The Sun will shine on the ball and illuminate it exactly as it illuminates the Moon.

Adapted from:

Foster, G.W. (1996). Look to the Moon. *Science and children.* 34(3), 30-33.

Braile, S. (1994). Moon phase modeling. In N.B. Ball, H.P. Coyle, & I.I. Shapiro (eds.), *Project SPICA.* Kendall/Hunt Publishing Co: Dubuque, Iowa.

Workshop 6: The Mind's Intelligences

In this workshop, you will explore Howard Gardner's theory of multiple intelligences and see his theory being applied in a variety of different classrooms. Gardner will also discuss the importance of the disciplines and share his thoughts on educational reform in America.

FEATURING

HOWARD GARDNER

Professor of Cognition and Education at the Harvard Graduate School of Education and the author of many books and several hundred articles, Howard Gardner is best known in educational circles for his theory of multiple intelligences. During the past fifteen years, he and his colleagues at Project Zero have been working on the design of performance-based assessments and education for understanding. Gardner's book, *Extraordinary Minds,* case studies of exemplary creators and leaders, was published in 1997, and his latest book, *The Disciplined Mind: What All Students Should Understand,* will be published in the spring of 1999.

Workshop 6 timeline

GETTING READY

30 minutes

30 minutes—Moon Discussion

By now you have had an opportunity to observe the Moon over an extended period of time. What patterns have you noticed about the behavior of the Moon? Do these patterns involve time? Shape? Location? What predictions can you make about the Moon's behavior over time?

Think about your learning style as it relates to the Moon Journal activity, and share it with your colleagues. Are there similarities in learning styles among the people in your group? Differences?

What connections can you make between your colleagues' learning styles and experiences with the Moon Journal and the learning that happens in your classrooms with your students?

WATCH THE WORKSHOP VIDEO

60 minutes

1. Think of a lesson you teach that always raises questions. Brainstorm ways you might respond using multiple intelligences as a tool to help students gain a better understanding.
2. Think of an analogy that you might use for a concept you want your students to understand. Try your analogy on your colleagues.

GOING FURTHER

30 minutes

30 minutes—Perspective

Here's a good entry point for a lesson on Sun/Moon/Earth relationships:

Choose a partner and sit on opposite sides of a table or desk. Place two or three objects on the table between you. Without moving from your seat, sketch the objects from your own perspective, from your partner's perspective, and from a bird's eye view.

When everyone has completed the drawings, discuss the following as a group:

What problems did you encounter?
What strengths did you need?
Which students in your class would excel in this activity?
Which students would have difficulty?

What additional activities or entry points could you build for this lesson that rely on other strengths?

Is it important for a student who does not have a particular strength to do an activity that requires that strength? Why or why not?

For next time

HOMEWORK ASSIGNMENT

Think about how you normally group students for activities, projects, seating, or other purposes. What criteria have you used in grouping? Make a list of the different ways you have used. Now consider ways you could group students according to Gardner's theory of multiple intelligences (MI). Do you think grouping students according to MI criteria would affect student performance? Try it!

Please bring a deck of cards with you to Workshop 7.

READING ASSIGNMENT

In preparation for Workshop 7, please read "Technology for Life-Long Kindergarten" by Mitchel Resnick. (All readings are included in the Appendix.)

MOON JOURNAL

You might want to take some time to look at the features on the surface of the Moon and consider the following questions:

Does the Moon's behavior affect our perspective of the features on the Moon?

Do features appear to "move across" the Moon from observation day to observation day?

Does the Moon's behavior affect the visibility of features we can see on the Moon?

Here are more suggestions for reflecting on your own learning:

What methods have you been using to make sense of your Moon observations?

Have you noticed any patterns in your learning behavior that you use in this kind of learning situation?

Suggested activity

Observing the Features of the Moon

SKETCHING FEATURES ON THE MOON

MATERIALS:

Pencil
Paper or sketch pad
Binoculars (optical)
Moon Map (p. 44)

INSTRUCTIONS

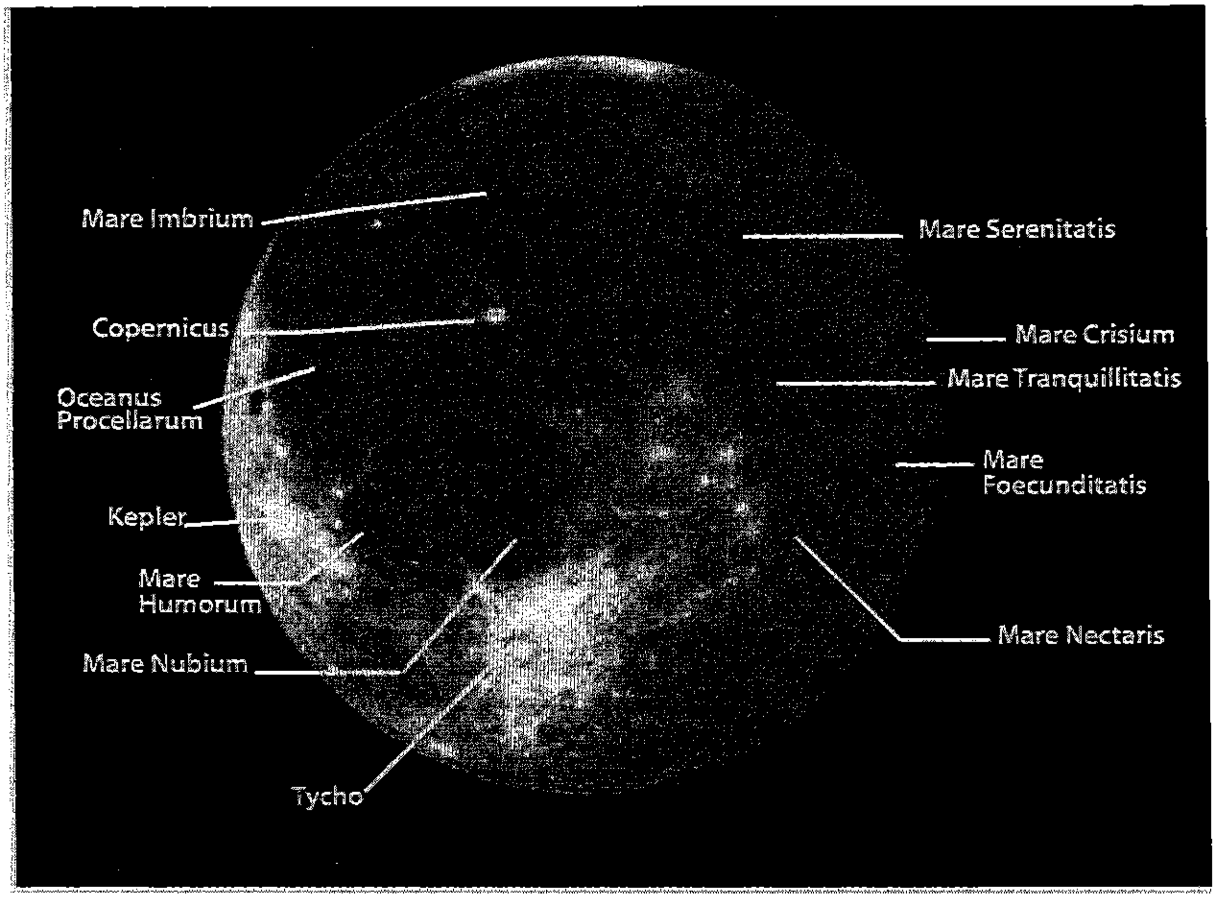
Before using the Moon Map to identify features on the Moon, sketch the features you observe. When the Moon is not full, you should notice that the Moon is divided by a line—the *terminator line*—that separates the Moon's sunlit side from its shadowed side. The features on the Moon's surface stand out best near the terminator line. These features are even more apparent when using high-powered binoculars. Use your Moon Map to help identify interesting features on the Moon.

To observe a feature on the Moon over time, use your Moon Map to identify a feature close to the "curved" edge of the lit portion of the Moon. Examine this feature over a week or two. Is the feature always visible? Does the feature change its relative position? Does the feature seem to "move" across the Moon or stay in the same place?

CHALLENGE

How do your observations help you to learn something about the revolution time of the Moon as compared with the rotation time of the Moon?

MOON MAP



Mare Imbrium
Copernicus
Oceanus Procellarum
Kepler
Mare Humorum
Mare Nubium
Tycho
Mare Serenitatis
Mare Crisium
Mare Tranquillitatis
Mare Foecunditatis
Mare Nectaris

Workshop 7: Design, Construction, and Technology

This workshop will focus on technology as an aid for learning. Mitchel Resnick will discuss the effect of technology on learning when students design and construct tools to support their own inquiries. You will see examples of teachers using technology in their classrooms and get a sneak peek at Resnick's newest learning tool—the cricket.

FEATURING

MITCHEL RESNICK

Professor in the Epistemology and Learning Group at the Media Laboratory at Massachusetts Institute of Technology, Mitchel Resnick studies the role of technological tools in thinking and learning and develops new computational tools that help people (especially children) learn new things in new ways. He is the author of *Turtles, Termites and Traffic Jams,* and is the cofounder of the Computer Clubhouse Project, a network of afterschool learning centers.

Workshop 7 timeline

GETTING READY

30 minutes

30 minutes—Card Sort

You were asked to bring with you a deck of cards. Shuffle the cards. Remove one card from the deck and set it aside without looking at it. Spread out the remaining cards, face up, so that all 51 faces are visible. Without touching the cards, determine which one is missing. Check your answer by looking at the card you set aside. (Each participant should do this activity individually.)

As a group, discuss the methods used to discover the missing card. How many different methods were there? Were some better than others? What constitutes a "better" method?

If time allows:

Repeat the exercise given above, but this time you may touch cards.

Repeat the exercise with a partner—both of you may touch the cards.

WATCH THE WORKSHOP VIDEO

60 minutes

1. Brainstorm ideas for a design activity in a unit you teach.
2. Think of a lesson you currently teach. How might the addition of technology benefit students' learning?

GOING FURTHER

30 minutes

SELF CHECK

30 minutes—Design a Sheet/Blanket Folder

Folding sheets and blankets neatly is easy when someone is around to help you, but hard for one person to do alone because of the size of the object to be folded. Design a device that would help someone fold sheets and blankets.

Discuss your design process. How did you decide what problems needed to be addressed? How did you go about addressing them? Did you learn anything from the process?

What can you take from this experience that you could apply to learning in your classroom? How might you incorporate a design activity into an upcoming lesson or unit that you have planned?

For next time

HOMEWORK ASSIGNMENT

Look for a newspaper, magazine or Web article about an education issue in a country other than the United States. **Bring the article with you to Workshop 8.**

Please remember to bring the concept map that you made in Workshop 3 with you to Workshop 8.

READING ASSIGNMENT

In preparation for Workshop 8, please read the summary of "Facing Consequences" by William Schmidt. (All readings are included in the Appendix.)

MOON JOURNAL

You might want to think about the following:

In what direction (north, south, east, west) does the Moon rise?

In what direction does the Moon set?

When does the Moon rise and set? Does it set earlier, later, or at the same time from one night to the next?

Suggested activity

Moon Phase Guide

If you know the directions in which the Moon rises and sets, a Moon Phase Guide is a useful tool for determining the time at which the Moon rises and sets.

BUILDING A MOON PHASE GUIDE

MATERIALS:

Moon Phase Guide template (p. 50)
Corrugated cardboard (15 cm x 15 cm)
Pushpin or thumbtack
Almanac, newspaper, or calendar
Scissors
Glue or paste

INSTRUCTIONS

1. Cut out both pieces of the Moon Phase Guide.
2. Glue or paste the larger piece to the center of the cardboard.
3. Orient the smaller piece on top of the larger such that the center points are aligned.
4. At the center point, push a pushpin or thumbtack through both template pieces and the cardboard.

USING A MOON PHASE GUIDE

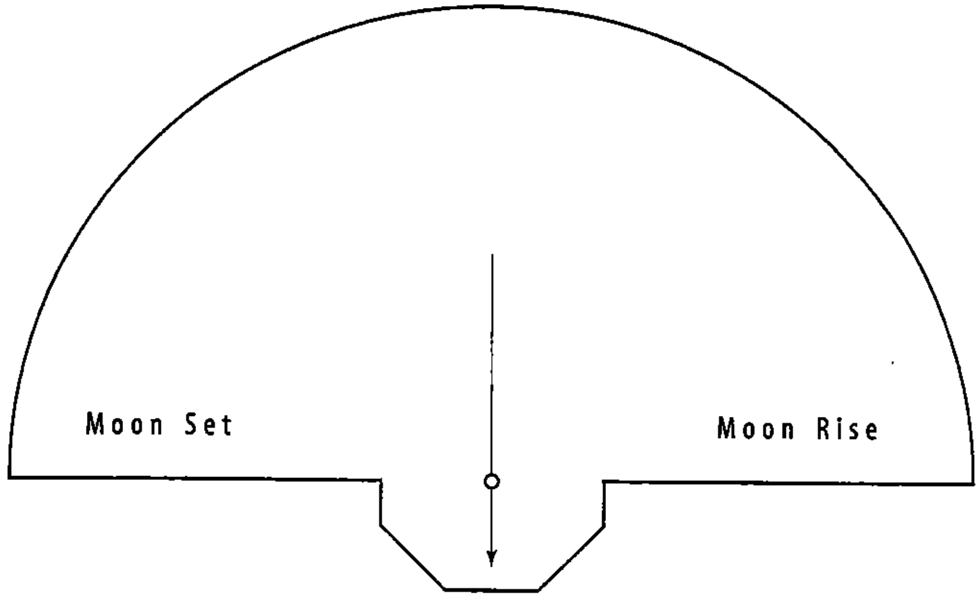
1. Determine the current Moon Phase (consult an almanac, newspaper or calendar).
2. Position the Moon Phase Guide so that the text is face-up and parallel to the ground.
3. Holding the half-circle in place, rotate the cardboard until the current Moon phase is directly under the **Moon Rise** portion of the half-circle.
4. Note the time the arrow on the half-circle is pointing to. This is about the time the current Moon phase rises.
5. Next, rotate the cardboard until the phase of the current Moon phase is directly under the **Moon Set** portion of the half-circle.
6. Note the time the arrow on the half-circle is pointing to. This is about the time the current Moon phase sets.

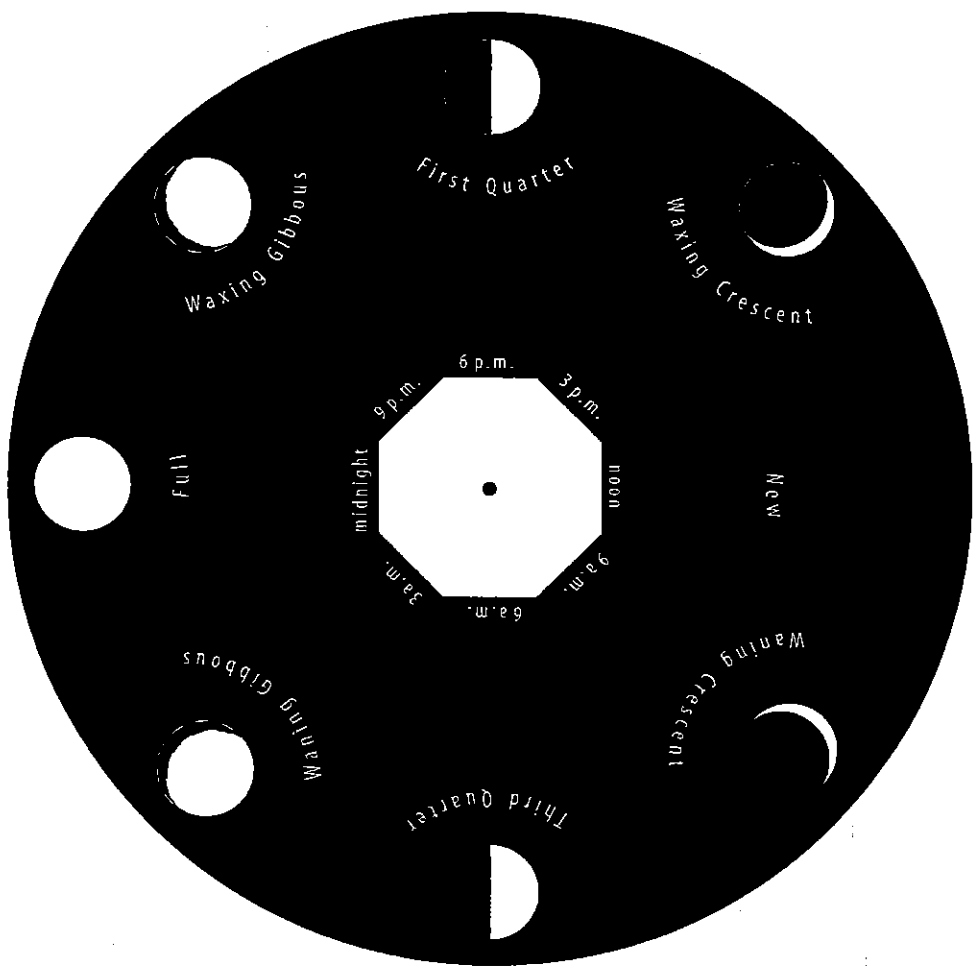
QUESTIONS

1. The Moon Phase Guide indicates that the Moon is visible for 12 hours each day. Is this accurate?
2. Why is there a predictable pattern to the changing appearance of the Moon?
3. How does the Moon Phase Guide work? What assumptions does it make about the Sun-Moon-Earth relationships in its design? What assumptions does it make about the directions of Moon rise and set.

Adapted from:

Becker, K. (1994). Moon phase dial. In N.B. Ball, H.P. Coyle, I.I. Shapiro (Eds.) *Project SPICA*. Kendall/Hunt Publishing Co.: Dubuque, Iowa


Moon Set
Moon Rise


First Quarter
Waxing Crescent
Waxing Gibbous
Full
New
Waning Gibbous
Waning Crescent
Third Quarter
6 p.m.
3 p.m.
9 p.m.
midnight
noon
3 a.m.
9 a.m.
6 a.m.

Workshop 8: The International Picture

In this workshop, you will have an opportunity to investigate various aspects of the Third International Mathematics and Science Study (TIMSS) other than the test scores themselves. William Schmidt will present differences in curricula, textbooks, and teaching practices around the world, and a group of community members will discuss how the TIMSS results reflect societal and cultural values.

FEATURING

WILLIAM H. SCHMIDT

University Distinguished Professor of Applied Statistics in the Department of Educational Psychology at Michigan State University, William Schmidt is the national research coordinator and executive director of the center that oversees the participation of the United States in the Third International Mathematics and Science Study (TIMSS).

Workshop 8 timeline

GETTING READY

30 minutes

30 minutes—In the News

You were asked to bring with you an article about education outside of the United States. Briefly share the topics of your articles. What kinds of issues do the articles focus on? How might you categorize the issues? Do these categorizations reflect education issues in the United States? What are the similarities? The differences?

WATCH THE WORKSHOP VIDEO

60 minutes

1. List the topic areas your students cover in math or science in the 3 years prior to arriving in your class and in the 3 years afterleaving your class.
2. If you were in charge of creating the national math or science standards, whom would you invite to the table?

GOING FURTHER

30 minutes

15 minutes—Revisit Moon Charts

Take a few moments to consider the changes and additions that you have made to the Moon Chart over the course of this workshop series. Discuss the following:

What were your major findings about the behavior of the Moon?

What discoveries surprised you the most?

Which of your prior beliefs were supported/challenged by your observations?

Creating the Moon Chart in Workshop 1 and updating it throughout the series allowed you to keep track of what you learned and how your beliefs changed as you observed the Moon and kept your Moon Journal. How do you (or could you) provide an opportunity for your students to follow their own learning about a topic?

15 minutes—How Far You've Come

Take out the teaching or learning concept map that you made in Workshop 3. Look at the Moon Chart and the Learning Chart that you and your colleagues made. How has your thinking about learning changed since this workshop series began? How will these changes affect your teaching?

Go around the room and share one thing that you plan to do in your classroom to apply what you've learned about learning.

Suggested activity

Moon Legends

Our scientific understanding of the Moon and its behavior has not always been what we currently accept to be true. Throughout history and across cultures, civilizations have developed what we know of today as legends and folklore as explanations of Moon observations and its behavior. Legends were the first scientific explanations. People would observe a phenomenon and then describe it with a story. People eventually began comparing different legends of similar phenomenon to find out which were most helpful in explaining what they saw. The following are stories developed by early cultures to describe possible reasons for the behavior of the Moon:

According to Central Mexican (non-Mayan) cultures, the Moon and the Sun were created at the same time when the two gods, Tecuciztecatl and Nanahuatzin threw themselves into the Fires of Creation and turned into two Suns. But the gods who organized this also threw a rabbit into the face of Tecuciztecatl, dimming his brightness, making him the Moon.

The Mayans believe the Moon Goddess to be a feisty woman. It is said that she once quarreled with her husband, the Sun, who became so angry that he poked out one of her eyes. That is why the Moon Goddess is dimmer than her spouse the Sun.

The Cherokee tribe of California tells the story of Father Sun and Mother Moon who lived inside Rock House. Their light did not shine from the sky, so the world was full of darkness. Coyote thought it would be a fun trick to dump some fleas on Father Sun and Mother Moon. Coyote got Gopher to help dig a hole through the soil into Rock House, and Rabbit to help shake a bag of fleas down the opening. The fleas soon covered Father Sun and Mother Moon. When they could no longer stand the fleas, Mother Moon flew out of the house, followed by Father Sun, and they began to race around the Earth trying to get rid of the fleas. That is why, to this day, the Sun follows the Moon across the sky.

The Snoqualmie tribe in Washington tells the story of a time when the sky was completely dark and there were two brothers, One Who Walks All Over the Sky, and Walking About Early. One Who Walks was sad to see the sky always dark so he made a mask out of wood and lit it on fire. Each day he walks across the sky wearing his fiery mask. At night he sleeps below the horizon and when he snores sparks fly from his mask and make stars. The other brother became jealous. He smeared fat and charcoal on his face, and makes his own path across the sky.

The Zunipu tribe of New Mexico and Arizona tells a story of a time when it was always dark, and always summer. Coyote and Eagle were hunting and they came across a tribe that had the Sun and the Moon in a box. After the people of the tribe had gone to sleep, the two animals stole the box. At first Eagle carried the box, but soon Coyote convinced Eagle to let him carry it. Coyote, being curious, opened the box and the Sun and the Moon escaped and flew up into the sky. This gave light to the land, but it also took away heat, which is why we now have winter.

QUESTIONS

1. What kinds of Moon behavior do the legends try to explain?
2. What descriptive features of the Moon or Moonlight, visible to the naked eye, are explained by the legends?
3. How are these legends related to the culture of the people who developed them and maintained them over the centuries?
4. Find out something about the people who developed the legends and relate these ideas to the reasons for the importance of each legend.

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Related Resources

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The Virtues of Not Knowing

ELEANOR DUCKWORTH

THE topic on which I was asked to write this article was, "The Nonpassive Virtues." At the time I thought that I understood what it meant, but when I sat down to write, I realized that I had no idea of what the *passive* virtues of the intellect would be. In matters of intelligence, with what could nonpassive virtues be contrasted?

It occurred to me, then, that of all the virtues related to intellectual functioning, the most passive is the virtue of knowing the right answer. Knowing the right answer requires no decisions, carries no risks, and makes no demands. It is automatic. And it is thoughtless.

Moreover, and most to the point in this context, knowing the right answer is overrated. It *is* a virtue—there is no debate about that—but in conventional views of intelligence it tends to be given far too much weight.

In most classrooms, it is the quick right answer that is appreciated. Knowledge of the answer ahead of time is, on the whole, more valued than the process of figuring it out.

Similarly, most tests of intellectual ability seek to establish what children have already mastered. Whether the tests are concerned with verbal ability, mathematical ability, general reasoning, or whatever, the task they demand of the child is to fill in the right blank and move on to the next. True, intelligence tests require that certain things be figured out, *but the figuring out doesn't count.* If the figuring out leads to the right answer, then of course the right answer counts. But no tester will ever know and no score will ever reveal whether the right answer was a triumph of imagination and intellectual daring, or whether the child knew the right answer all along. In addition, the more time the child spends on figuring things out on the test, the less time there is for filling in the right answers; that is, the more you actually *think* to get the right answers on an intelligence test, the less intelligent the results will look.

WHAT IS IT?

Eleanor Duckworth is currently lecturer at the Faculté de Psychologie et des Sciences de L'Education, Université de Genève, Switzerland.

Ms. Duckworth has been a staff member of the Elementary Science Study, evaluator of the African Primary Science Program, and founding director of the Lighthouse Learning Program in her home province of Nova Scotia, Canada. Her writings include numerous articles on children's learning, and she has also prepared a film for teachers, *Learning About Thinking and Vice Versa.*

"The Virtues of Not Knowing," by Eleanor Duckworth. *The National Elementary School Principal,* Volume 54,

I would like to give some attention to what is involved when the right answer is *not* already known.

During the last few years, in Geneva, Switzerland, Barbel Inhelder, Hermine Sinclair, and Magali Bovet have done some important work in trying to shed light on what happens when a child takes himself from one level of understanding to another.* As part of this project, they would meet with a child several times over a period of one to three weeks (depending on the experiment), each time presenting him with situations in which the contradictions in his own thoughts would be brought into relief. In this way they could witness his attempts to put his ideas together in different and more satisfactory ways. In no way, however, did their procedure seek to teach children "the right answer." They sought instead to give children the opportunity to explore their ideas and to try to make more sense of them.

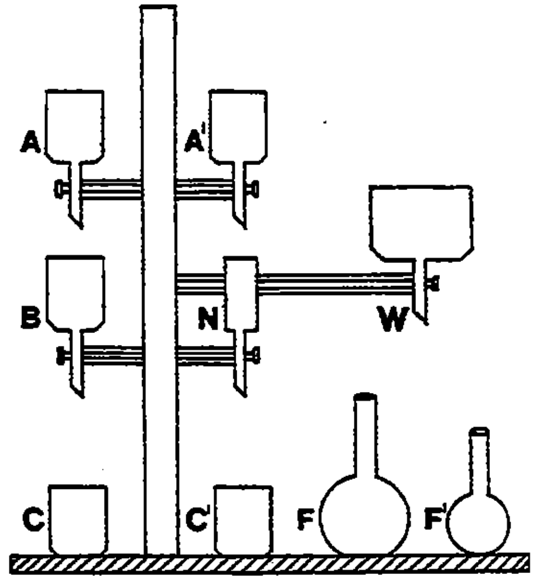
Among the most fascinating aspects of the book are the lengthy accounts of children grappling with their own non-understanding—occasions when the children knew that something was not quite right and tried to do something about it.

One of the experiments deals with the realization that an amount of liquid remains the same quantity, even though it is made to look different; for example, when it is poured into a glass of a different shape. The apparatus Inhelder and her colleagues used is shown in the drawing. Small valves allow the liquid to run from upper glasses to lower ones. The glasses A, A', C, and C' are all the same. In the middle layer, glasses of different dimensions are used: B (the same as A and C), N (narrow—as shown), and W (wide—the same height, but wider than B). The flasks F and F' were used to fill the top glasses.

The following is an account of Jac, a boy nearly six years old.

To begin the first session, A and A' are filled to the same level, and Jac correctly anticipates that the quantities and levels of the liquids in C and C' will be the same. As they proceed to let the liquids run, he remarks spontaneously, "Gee, that's high there [in N]. But I poured with the same bottle [F]. I poured all of it."

* *Apprentissage et Structures de la Connaissance* (Paris: Presses Universitaires de France, 1974).



During the second part, a real conflict is born. A and A' are again filled to the same level. A is emptied into B, and then Jac is told to run the same amount from A' into N. "How can I do it?" he asks. "If I stop at the same place [that is, the same levels in B and N], I won't have the same amount to drink at the end [in C']. Look, I left a bit up there [A']. To get the same at the end, I have to pour all of it. But then that doesn't go up the same." He pours it all into N, and remarks, without any prompting from the investigator, "It looks like too much, doesn't it?"

The wider glass [W] is then substituted for B, and Jac is asked to do the same thing again. He is visibly perplexed. "That's really funny. If I don't leave that little bit up there, I never get the same thing here [indicating the levels in W and N]. In that one it's so big, and in the skinny one. . . . But that *has* to be just as much liquid; it's all there. I know! It only *looks* like there's more! In the skinny glass, the liquid is squeezed in, so it has to go up. In the big one it's spread out!"

To begin the second session, the glasses B and N are behind a screen when the liquid is poured into them—equal amounts from A and A'. Jac predicts how high the levels will be, and then the screen is removed. He seems delighted to see his predictions confirmed. "I know, it's like the last time! There's always the same amount to drink; it just looks like there's more. The liquid just goes into the glass different."

Next, A is filled from F and A' from F', so there are different quantities to begin with, but the levels are the same once they have flowed into B and N. Jac is bemused for a moment when he sees them in B and N. "How come? I poured the little bottle in there [A'] and now it's the same. Oh, I know! It's still the same! You'll see at the end. . . . Wait! I know, all the time it's still less on that side [the right-hand side]. There wasn't any more in the middle. There can't be!"

"Gee!" "How can I do it?" "That's really funny." "How come. . . ?" "Wait—wait!" "Oh, I know!" Surprise, puzzlement, struggle, excitement, anticipation, and dawning certainty—those are the matter of intelligent thought. As virtues, they stand by themselves—even if they do not, on some specific occasion, lead to the right answer. In the long run, they are what count.

One can also find such virtues in the classroom. I once watched a class of ten-year-olds, while they learned about pendulums. In the class, there was a boy named Alec who would be any teacher's joy. He was full of ideas, articulate about them, and thoughtful and industrious in following them through. During the course of the pendulum study, Alec, working in his usual thorough and competent way (with a partner in tow), pursued many questions that nobody else had the interest or the patience to work through. The rest of the class occasionally took an interest in what he had been doing, but usually he and his partner went their own way.

After a number of weeks, the class watched some film loops, in which a pendulum dropped sand as it moved, thus leaving a record of its travels. One question the students considered was, when a pendulum is swinging back and forth, does it slow down at each end of its swing, or does it maintain the same speed and simply change direction? Alec, who was something of a mathematician by inclination, finding merit more readily in deduction than in experience, quickly maintained that the pendulum did not slow down at the ends, "because there's no reason for it to." The other children tended to agree, because that first opinion came from Alec. The teacher said nothing, but continued playing the loop in which the sand was falling into a row of straws.

After a while, one child said, "I don't get it. Why isn't it the same all along the straws, then?" There was a silence again as they continued to watch. Another child said, "There's more at the ends; it piles up at the ends." Other remarks came: "How come it isn't higher in the middle—because it goes back and forth over the middle?" "It probably goes fast over the middle—fast over the middle and slows down at the ends." "Besides, how can it stop without slowing down?"

Gradually, the comments added up—always directed, at least implicitly, to Alec's idea. At last one child dared to commit himself: "It has to be slowing down at the ends." And one by one, each child committed himself to an opinion that was the opposite of Alec's. Alec, who was used to being the only one to hold to a given opinion, was unconvinced for a long time by their reasons. Long enough so that almost every child in the class, independently, summoned the intellectual courage to maintain a position that was opposite to Alec's—and even to argue with him. Until finally, Alec was convinced by their reasons, and quietly changed his mind.

WHAT IS IT?

The class played out in public view virtues concerned with courage, caution, confidence, and risk. The courage to submit an idea of one's own to someone else's scrutiny is a virtue in itself—unrelated to the rightness of the idea. Alec's idea was wrong, but it was his customary willingness to propose it and defend it that paved the way to a more accurate idea. The other children were right, but they would never have arrived at that right idea if they had not taken the risk—both within themselves and in public—to question Alec's idea.

There was an epilogue, too. The next and last time the teacher visited that class, Alec put forth another idea during public discussion, again with easy confidence that it would work. It didn't. It was discarded and the class looked for others. On neither of those occasions did Alec suffer, either in his own eyes or in the eyes of anyone else. He had never been arrogant when his theories worked out well, so that he felt no disgrace when an idea failed. There was neither false modesty nor defeat when he said to the teacher as she left that day for the last time, "You know, I've learned one thing in this class—I don't always have such great ideas."

Alec was used to defending a theory that he judged sound. What was new for him was the honest recognition that some of his thoughts might bear a closer look before deserving his commitment to them—and they might even benefit from the scrutiny of other children.

In both of these examples, problems were set for the children, and we saw what was involved in trying to resolve them. Another whole domain of virtues we have not even mentioned is that of sitting alone, noticing something new, wondering about it, framing a question for oneself to answer, and sensing some contradiction in one's own ideas—in other words, all of those virtues that are involved when no one is present to stimulate thoughts or act as prompter.

The virtues involved in not knowing are the ones that really count in the long run. What you do about what you don't know is, in the final analysis, what determines what you will ultimately know.

It is, moreover, quite possible to help children develop these virtues. Providing occasions such as those described here, accepting surprise, puzzlement, excitement, patience, caution, honest attempts, and wrong outcomes as legitimate and important elements of learning, easily leads to their further development. And helping children to come honestly to terms with their own ideas is not difficult to do. There was nothing particularly skillful or subtle in the roles of the adults in these examples.

The only difficulty is that teachers are rarely encouraged to do that—largely because standardized tests play such a powerful role in determining what teachers pay attention to. Standardized tests can never, even at their best, tell us anything other than whether a given fact, notion, or ability is already within a child's repertory. As a result, teachers are encouraged to go for right answers, as soon and as often as possible, and whatever happens along the way is treated as incidental.

It would make a significant difference to the cause of intelligent thought in general, and to the number of right answers that are ultimately known, if teachers were helped to focus on the virtues involved in not knowing, so that these virtues would get as much attention in classrooms from day to day as the virtue of knowing the right answer.

WHAT IS IT?

page 15: measuring spoons
page 16: Anchor fence
page 17: wheat
page 18: flower petals
page 19: tree bark
page 20: elephant's trunk
page 21: oranges
page 30: light bulb
page 45: spokes of an umbrella
page 47: neck of a guitar
page 53: tuning fork
page 55: circus tent
page 63: sweetgum seedpod
page 65: crinkled aluminum foil

8

Assessing "Imperfect" Conceptions

HUBERT DYASI

A VIEW OF ELEMENTARY SCHOOL SCIENCE

Assessment of children's progress in elementary science is embedded in an educational approach and serves clear purposes. In this article I shall describe my preferred approach to elementary science learning and outline what I think are appropriate data for assessment.

Children achieve a better understanding of the world by continually building and reinterpreting their direct knowledge. Their conceptions of the world undergo change as they grow and gain more direct experience with the physical world and with the world of symbols and ideas. Conceptual imperfection and continual refinement are, therefore, part and parcel of elementary school science learning. At the City College Workshop Center in New York, we view children's learning of elementary school science as encompassing content and approach. The content is found in common materials and phenomena that we encounter, and the approach is inquiry built around making meaning from observations and experience.

Direct experience with phenomena of the world connects the content of elementary science with children's experiences and observations outside the classroom. This connection reconfirms that science is a continuing search for underlying commonalities in apparently disparate phenomena, and an intense engagement with things that arouse our curiosity.

In an illustration of this approach, Jos Elsgeest (1969), a Dutch science educator who worked for many years in African science education, engaged African children studying the larval stage of the ant lion, an insect that resembles a dragonfly. The children's curiosity had led them to wonder about

An earlier version of this article appears in Hein, Ed. (1990). The Assessment of Hands-On Elementary Science Programs. *NDSG*, August, pp. 248–262.

Reprinted by permission of the publisher from Jervis, K., & Montag, C. (Eds.), PROGRESSIVE EDUCATION FOR THE 1990s: TRANSFORMING PRACTICE (New York: Teachers College Press, pp. 101-110.

observable characteristics of the ant lion, and to devise ways to answer their own questions. A transcript of a class discussion held after several observation sessions gives a flavor of the approach (T refers to the teacher; C1–C5 refer to five children) (Elsgeest, 1969, p. 3):

T: Do you remember what you have already learnt about the ant lion [from the ant lion itself]?
C1: They live in the soil.
C2: They move backwards.
C3: They like the sand.
C4: They cannot live outside the sand.
T: How do you know?
C4: I tried it. I put it in my tin without sand, and it died.
T: After how long did it die?
C4: After three days.
T: Why do you think it died outside the sand?
C4: It cannot live outside the sand.
C5: It could not eat.
T: Now, that is a big problem: what do ant lions eat?

The children learned directly where the ant lion lives and about its locomotion. The record went on to show that among other things, they had also learned what the ant lion eats, how it catches its prey, whether it can see, and about how many legs it has.

Prominent, experienced scientists support our view of elementary school science as a precursor to authentic science inquiry and practice. Philip and Phylis Morrison (1984) have said quite simply, "You can't talk about science and remain solely in the domain of symbolic discourse. You require some contact with that substance of which science is a symbolic representation" (p. 4). Arons (1983) expressed the point in these words:

> Experience makes it increasingly clear that verbal presentations—lecturing to large groups of intellectually passive students and having them read text material—leave virtually nothing in the student's mind that is permanent or significant. Much less do they help the student attain what I consider the marks of a significantly literate person. (p. 92)

David Hawkins (1983) put the issue as follows: "There is a marvelous continuity between the worlds of children's experience and the adult worlds of the arts, of the sciences and mathematics, of conduct and social life. This community is one of cumulative learning" (p. 65).

At the City College Workshop Center, elementary school science learning encompasses three related processes: primary inquiry into a phenomenon of nature, symbolic representation of observations, and the ability to see patterns.

Inquiry involves direct, first-hand experiences with a selected piece of the natural world. If the selection is pendulums, children have direct experiences with pendulums by making and examining them, thus getting to know the parts of the pendulum. They observe pendulum motion and how it varies under different configurations, and identify periodic motion in nonclassical pendulums, perhaps by looking at the arms of a runner.

Observations children make may initially be general, but will often be refined as a result of a teacher's quest for greater specificity. For example, children will describe an insect with wings and legs and then begin to see an insect with so many pairs of wings, a specific shape, patterns of colors, and venation, and with specific points of attachment to the insects' body. They likewise arrive at detailed observations of legs: jointedness, number of pairs, smoothness or roughness, softness or hardness, and so on. The overall significance of primary inquiry is that children devise valid and reliable ways of obtaining information directly from nature, and actually do obtain it.

The second part of the process—symbolic representation—takes various forms: words, drawings, sound recordings, numbers, tracings, and photos. Asking children to represent some aspect of nature in symbolic form encourages them to observe details more closely for the purpose of keeping an accurate record and communicating observations.

The final process, children describing patterns as a result of their observations and representations of nature, engages them in generating knowledge and in developing concepts. At one level, children might see similarities among different things, and at a slightly deeper level, they may invent categories of attributes shared by objects or organisms. They may also begin to see patterns emerge under varying conditions or configurations. As children go beyond trial and error, the process involves studying descriptions, manipulating variables, and conducting tests to yield more descriptions. Children then create an organizing scheme to establish order from the descriptions, and draw conclusions or abstractions based on evidence. The abstractions go further than lists of observations and representations to careful operational statements that provide a basis for making predictions and for developing additional understandings.

There is a difference, of course, between scientists' science and children's science. The difference resides in children's ideas and frames of reference on the one hand, and of scientists on the other. A classroom example in which children were allowed to reveal their science understandings shows the relationship between observation and a frame of reference. Hein (1970) followed fifth graders studying linear motion of differently shaped objects down an inclined plane. The children had been asked to compare ways the different objects moved down the inclined plane; and they did, but not in ways the science educators expected them to do. The children raced the objects against one another to see who the winners and who the losers were. No matter what

Figure 8.1. Children's Scheme for Classifying Insects

CATEGORY	CHARACTERISTIC	EXAMPLES
Live communally	Very small, build houses	Wasp, white ant
Attack intruders	Eat other insects or powdery things	Bee, safari ant
Do not bite	Humble	Mantids, butterfly, ant lion, earthworm
Make honey	Lay eggs, obtain food from flowers, suck food, hairy legs	Bee, butterfly
Have three parts	Short wings, eat tender leaves, big eyes, winged	Wasp, house fly, termite, bee
Live underground	No eyes	Ant lion, white ant, small black ant, safari ant
Live in trees	Eat fruits, bite	White ant

questions the educators asked or in what direction they tried to lead the children, the children persisted in looking at the events as races. Within the frame of "races," children observed some events and failed to notice others which would be important in a different frame of reference. The important observation to children was spotting the winners; ties were irrelevant. Hein concluded logically and reasonably: "These children do not have a statistical view of data and scientific observation. Instead they have a particulate view of events. Each observation has its independent existence, each observation could decide the contest" (p. 87). Looking for winners in this activity is not what a scientist would do. Scientists would attend to "ties" in their frame of reference because they are interested in probabilities of independent events.

Children's science tends to draw understandings directly from the nonidealized conditions we all know, whereas scientists' views relate to established canons of knowledge drawn from idealized or controlled laboratory conditions. For example, children know that in free fall, heavy objects fall faster than lighter ones. Scientists make the same observations; but children's explanations of this phenomenon will differ from the scientists' because children's frame of reference is centered only on the weight of the objects and does not encompass observations of free fall in a vacuum. The different frames of reference or presuppositions with which children and scientists approach this observation result in different "facts," different trials of one factor or another, and different degrees of elaborateness of investigations.

If children's frame of reference of winners and losers is flawed as a basis for scientific understanding of rolling objects down inclined planes, it has to be improved by creating an interest in examining ties which still need to be

Figure 8.2. A Child's Classification of Caterpillars

COLOR	FATNESS	HAIRY	FOUND ON	SAMENESS
Green	Thin	Not hairy	Hawthorn	Not the same
Yellow and grey	Fat	Bit hairy	Hawthorn	
Brown	Fat	Hairy	Dock leaf	Not the same
Brown	Medium	Bit hairy	Hawthorn	Same

explained. Such an examination might lead children to consider frames of reference that allow for a more comprehensive and reliable description of observed events. They might go beyond "naive" notions or theories to careful operational statements that lay ground for predictions and for broader understandings. A close look suggests that children's work is important in assessing their progress in science inquiry.

Children's Work

A fifth grade class which had been looking at insects for several lessons developed its own classification scheme (see Figure 8.1) and a "key" for identifying insects found locally. A person looking at the children's classification scheme might be struck by its unusual basis and by errors it contains. For example, a person might think that the first column is not necessary—that the categories are actually also characteristics in some sense. One notices also that some of the organisms belong to more than one "class." From the Linnean frame of classification (the genus and species frame of reference) earthworms should not be included because they are not insects. These are legitimate sources of concern but the concern must not overshadow the power of the children's creation of a scheme (Science Education Program for Africa, 1978).

Independently of these fifth grade children, other children in an elementary school class in England engaged in a similar science learning activity. One of them developed the classification scheme shown in Figure 8.2 (Rowland, 1984, p. 27).

In this classification activity the teacher reported that the child *first thought* about the attributes he wanted to use and then examined the specimens over and over again and selected those that share the attribute. This thinking about an embracing attribute from discrete observations is a very bold and constructive intellectual activity whether it is done at the frontiers of a discipline or, as in this case, at earlier stages of learning. The action signifies the interpretations of nature on the basis of observations, representations, and understanding of the selected organisms in the environment.

The creation of an interpretive scheme shows that the children have gone beyond particular examples to think of generalizations that can be supported by demonstrable observations. What remains to be done to further their science development is no small task; it is to encourage them to be willing to refine and modify their scheme, and to make finer distinctions. Before children can evaluate the usefulness of any scheme, however, they would have to use it extensively. From that use, perhaps they would recognize problems with a scheme that does not, for example, discriminate well among things that are very different from one another in some important respects. In time, they might see the value of seeking guidance from schemes developed by others. Perhaps as they observe other living things closely, they will look at the structural characteristics of the organisms in order to make fine classification distinctions. They will recognize their earlier schemes as first approximations that were useful for gaining a general idea and for laying a foundation for a coherent picture.

Observations need not be represented only in prose, drawings, and tables; they can be represented in verse, as the 10-year-old Leo's poem show. (Leo—not his real name—did this work at the Prospect School, Bennington, Vermont [The Prospect Archive, 1984]):

It's a Spider

Moving through the night
As if always in flight
From some unseen enemy.
In the summer webs on trees
In the fall webs in the leaves
In the winter you die on out
In the spring your children
Search for a new home.

There is a sense here that Leo has focused on the spider not momentarily, but over an expanse of time and space. He has arrived at the notion of the physical home (the web) located in a broader habitat—the tree at one time and the leaf at another. The life cycle is captured by the child: life of the spider in the summer, fall, and winter and then the young ones appear in the spring. Unstated, but understood is that in the summer they become adults, that will presumably die in the winter. The young ones have the task of building a home or searching for one. The great explosion of life in the spring and the end of a lifetime in the winter have been duly noticed and recorded by the child. *That* is the essence of observation to make meaning (Carini, 1979).

Documenting Children's Inquiry Work

Children have a natural inclination to make connections and to create schemes that account for perceived relationships. Previous examples of children's work

indicate that children can generate knowledge directly from objects of nature; such knowledge goes beyond mere speculation and guessing. Children can obtain information from direct experience with concrete natural phenomena through systematic manipulation and observation. They can utilize symbolic material to represent the observations faithfully, and make relevant abstractions from the representations. The challenge for assessment is to find strategies and mechanisms that portray this development in elementary science learning.

Documentation of children's work over *significantly long periods of time* is one of the best sources for assessing children's progress in elementary school science inquiry. The documentation can be obtained through the research technique of observing and recording a single child's experiences and responses. Although this method yields invaluable information for assessment purposes, it cannot be used consistently by classroom teachers who have responsibility for *all* children in their class for *only* nine months. But this technique can be modified to meet these constraints. The records of children's work at The Prospect Archive and Center for Education and Research are an excellent example of such a modification.

The Prospect Archive is a unique collection of individual children's drawings, writings, constructions, and other artifacts spanning an average of six to eight years of a child's school experience. The material on each child also includes a teacher's weekly statements about the child's educational activities, as well as a general summary covering each term. Below is an excerpt from a teacher's general summary about Leo, the child whose work has been cited above:

> He (Leo) builds intricate structures all of which have long explanations to go with them. One building of (Leo's) was...a building on another planet complete with laboratory, energy sources, water systems, solar collectors, secret passageways with trap doors. (Leo) has a natural sense of balance and symmetry....He is very inventive with wood and thinks up very original projects for himself to do. He built a base for a star ship. For this he invented a pivotal cannon that could move up and down and around. It was very impressive because he had come up with the whole thing completely independently. (The Prospect Archive, 1984, p. 54)

These evaluative statements are part of the data attached to the child's work. Interested persons can have access to the entire portfolio to make their own judgments. The teacher's statements do not make reference to the inquiry process associated with these activities, but there could have been such reference had the teacher included science inquiry as a major focus of the child's activities. However, the teacher did view making representations of objects as a very important activity for the child, hence the following comments:

> (Leo's) drawings often express his mechanical interests. They are often cross sections of buildings revealing all the inner networks of stairways, water systems, energy systems, and structural supports. His drawings are striking for the detail and depth. (p. 54)

The teacher's comments indicate quite vividly what a close observer Leo is; the comments lead us to look at the child's work directly to satisfy our curiosity about it.

Another mechanism for assessing development in elementary science learning is the documentation of group activities within a class over extended periods in the form of a "teacher's journal." In this case, work of groups of children is accumulated over time, thus creating a "bank" of detailed material encompassing their science learning activities. Included with the children's work are their teachers' perceptions and reflections about the work. The children's work cited above can be used to make inferences about the children's progress in science learning. *Juba Beach* (1971), a teacher's journal prepared for and published by the African Primary Science Program, is an example of such a journal. The journal includes children's descriptions of their science inquiry activities complete with written accounts, diagrams, and questions related to the organisms the children studied along a beach. The teacher's comments, interspersed in the children's own accounts, are informative. For example, in *Juba Beach* the teacher wrote:

> The general topic of beaches and sea integrated many experiences of learning. The children found and observed a wide variety of animals. They examined rocks and shells and sand. They tasted and tested water for salt content. They counted waves and the flow of rivers and talked to fishermen. The challenges were without limit...The events of this unit encouraged them to find answers to new questions. They wanted to learn and because of this they used and developed their skills—they measured, weighed, compared and counted, they kept notes and discussed their findings. For me, their own evaluations and this record book tell more about the progress of the children than any written examination I might have given them.

Computer technology can be used to build a data bank based on children's work which can provide evidence of the quality of their participation in science inquiry activities. In such cases the computer is a tool that children use to record the observations, experiments, and abstractions derived from their science investigations. The records can be retrieved by the children, the teacher, or by someone else interested in them. The Bank Street College of Education's Center for Children and Technology in New York City has done interesting work in this respect. In the *Earth Lab* project, children work in groups to do earth science inquiries; they collect data and later share their

findings. The Center's project *INQUIRE* is a software design that makes it possible for children to keep notes, and record their ideas, plans, guesses of expected findings, and findings while engaged in inquiry activities on sports physics. As a result, it is possible for children to create their portfolios as they progress in their elementary school science learning activities during science investigations (McCarthy, 1989).

Another interesting use of computer technology in elementary school science learning which has a great potential as a documenting mechanism for assessment purposes is *The National Geographic Kids Network*. This project for grades four through six is carried out by Technical Education Research Centers and combines the use of computers with telecommunications. Children in the network conduct experiments in their local areas, such as collecting data on acid rain. The telecommunications network links them with children in other localities by sending the results of their local experiments to a central computer. Through the network, children in various parts of the world can discuss their findings with their peers and work collaboratively in a manner similar to how a research team works together. Although many classrooms might not have easy access to a telephone line, the computer component of the activities can be good for recordkeeping.

The question is: Who assesses this work? The answer is teachers. Most documentation described here can be done by suitably educated teachers enjoying unfettered professional judgments. They would use prepared assessment guidelines indicating how the children's work is to be judged. The guidelines would be faithful to the advocated science approach, both sufficiently flexible and unambiguous. Carefully selected panels including teachers, science educators, child development specialists, leading scientists, and school children would prepare these crucially important guidelines. Since community schools are local institutions, groups of teachers at the local level, assessment specialists, science educators, and if possible, outstanding scientists would come together to examine children's work. Based on that examination they would prepare detailed reports describing the work and indicating how it was assessed. It would be left to the local school districts' or the state's discretion to make assessments by child, grade, school, district, or a combination of all those elements. For purposes of comparison across school districts, samples of assessed children's work could be examined by panels of teachers and assessment specialists drawn from the districts, with additional members drawn from other states. These panels would also prepare detailed reports on the documents they examined. These informative reports would be used widely to improve elementary school science instruction. Tests would not be eliminated; instead they would be restructured to focus on children's demonstrated capability to make sense of observations derived from physical materials presented to them.

I have portrayed elementary science education as focusing on children's engagement in organized inquiry with natural phenomena in their surroundings. I have also implied that science inquiry requires a considerable density of often repeated experience over long periods of time. I view one major purpose of assessment as support for quality instruction in science inquiry. The examples of children's work indicate that children are capable of conducting inquiries into nature, but are still developing "imperfect" conceptions by adult scientific standards. Through children's work, one gains insight into their developing art, skill, and knowledge of doing science. I am calling, therefore, for assessment that portrays children's continuing development in science inquiry through appropriate, practical, concrete investigative activities; and children's capacity to communicate their understanding by the questions they raise about nature, by the observations they choose to make, and through the symbols they devise. The willingness to document such data will not come about until it is accepted that elementary school children's inquiries are valuable starting and continuing points for science inquiry instruction, and that teachers can play a large role in assessment activities.

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Beyond the IQ: Education and Human Development

Developing the Spectrum of Human Intelligences

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Allow me to transport all of us to the Paris of 1900—La Belle Epoque. Around 1900 the city fathers of Paris approached a psychologist named Alfred Binet with an unusual request: Could he devise some kind of a measure which would predict which youngsters would succeed and which would fail in the primary grades of Paris schools? As everybody knows, Binet succeeded. He produced a set of test items which could predict a child's success or failure in school. In short order, his discovery came to be called the "intelligence test"; his measure, the "IQ." Like other Parisian fashions, the IQ soon made its way to the United States, where it enjoyed a modest success until World War I. Then, it was used to test over one million American recruits, and it had truly arrived. From that day on, the IQ test has looked like psychology's biggest success—a genuinely useful scientific tool.

What is the vision that led to the excitement about IQ? At least in the West, people had always relied on intuitive assessments of how smart other people were. Now intelligence seemed to be quantifiable. You could measure someone's actual or potential height, and now, it seemed, you could also measure someone's actual or potential intelligence. We had one dimension of mental ability along which we could array everyone.

The search for the perfect measure of intelligence has proceeded apace. Here, for example, are some quotations from an ad for a widely used test:

> Need an individual test which quickly provides a stable and reliable estimate of intelligence in four or five minutes per form? Has three forms. Doesn't depend upon verbal production or subjective scoring. Can be used with the severely phys-

This article is based on an informal talk given at the 350th anniversary of Harvard University on September 5, 1986. It has been edited only in the interests of greater clarity. No formal references have been included. The reader interested in documentation of the theory of multiple intelligences is referred to my book *Frames of Mind: The Theory of Multiple Intelligences* (New York: Basic Books, 1983). More recent articles, which treat educational implications of the theory, are: Joseph Walters and Howard Gardner, "The Development and Education of Multiple Intelligences," in *Essays on the Intellect*, ed. Frances Link (Washington, DC: Curriculum Development Associates, 1985): and Joseph Walters and Howard Gardner, "Multiple Intelligences: Some Issues and Answers," in *Practical Intelligences*, ed. Robert Sternberg and Richard Wagner (New York: Cambridge University Press, 1987). The work reported in this article was supported by the Rockefeller Foundation, the Spencer Foundation, and the Bernard Van Leer Foundation.

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ically handicapped (even paralyzed) if they can signal yes or no. Handles two-year-olds and superior adults with the same short series of items and the same format. Only $16.00 complete.

Now, that's quite a claim. Arthur Jensen suggests that we could look at reaction time to assess intelligence: a set of lights go on; how quickly can the subject react? Hans Eysenck suggests that investigators of intelligence should look directly at brain waves.

There are also, of course, more sophisticated versions of the IQ test. One of them is called the Scholastic Aptitude Test (SAT). It purports to be a similar kind of measure, and if you add up a person's verbal and math scores, as is often done, you can rate him or her along that dimension. Programs for the gifted, for example, often use that kind of measure.

I want to suggest that along with this one-dimensional view of how to assess people's minds comes a corresponding view of school, which I will call the "uniform view." In the uniform school, there is a core curriculum, a set of facts that everybody should know, and very few electives. The better students, perhaps those with higher IQs, are allowed to take courses that call upon critical reading, calculation, and thinking skills. In the "uniform school," there are regular assessments, using paper and pencil instruments, of the IQ or SAT variety. They yield reliable rankings of people; the best and the brightest get into the better colleges, and perhaps—but only perhaps—they will also get better rankings in life. There is no question but that this approach works well for certain people—Harvard is eloquent testimony to that. Since this measurement and selection system is clearly meritocratic in certain respects, it has something to recommend it.

But there is an alternative vision that I would like to present—one based on a radically different view of the mind, and one that yields a very different view of school. It is a pluralistic view of mind, recognizing many different and discrete facets of cognition, acknowledging that people have different cognitive strengths and contrasting cognitive styles. I would also like to introduce the concept of an individual-centered school that takes this multifaceted view of intelligence seriously. This model for a school is based in part on findings from sciences that did not even exist in Binet's time: cognitive science (the study of the mind), and neuroscience (the study of the brain). One such approach I have called my "theory of multiple intelligences." Proceeding rapidly, I will now tell you something about its sources, its claims, and its educational implications for a possible school of the future.

Dissatisfaction with the concept of IQ and with unitary views of intelligence is fairly widespread—one thinks, for instance, of the work of L. L. Thurstone, J. P. Guilford, and other critics. From my point of view, however, these criticisms do not suffice. The whole concept has to be challenged; in fact, it has to be replaced.

I believe that we should get away altogether from tests and correlations among tests, and look instead at more naturalistic sources of information about how peoples around the world develop skills important to their way of life. Think, for example, of sailors in the South Seas, who find their way around hundreds, or even thousands, of islands by looking at the constellations of stars in the sky, feeling the way a boat passes over the water, and noticing a few scattered landmarks. A word for intelligence in a society of these sailors would probably refer to that kind of navigational ability. Think of surgeons and engineers, hunters and fishermen, dancers and choreographers, athletes and athletic coaches, tribal chiefs and sorcerers. All of these different roles need to be taken into account if we accept the way I define intelligence—that is, as the ability to solve problems, or to fashion products, that are valued in one or more cultural settings. For the moment I am saying nothing about whether there is one dimension, or more than one dimension, of intelligence; nothing about whether intelligence is inborn or developed. Instead I emphasize the ability to solve problems and to fashion products. In my work I seek the building blocks of the intelligences used by the aforementioned sailors and surgeons and sorcerers.

The science in this enterprise, to the extent that it exists, involves trying to discover the right description of the intelligences. What is an intelligence? To try to answer this question, I have, with my colleagues, surveyed a wide set of sources which, to my knowledge, have never been considered together before. One source is what we already know of the development of different kinds of skills in normal children. Another source, and a very important one, is information on the ways that these abilities break down under conditions of brain damage. When one suffers a stroke or some other kind of brain damage, various abilities can be destroyed, or spared, in isolation from other abilities. This research with brain-damaged patients yields a very powerful kind of evidence, because it seems to reflect the way the nervous system has evolved over the millennia to yield certain discrete kinds of intelligence.

My research group looks at other special populations as well: prodigies, idiot savants, autistic children, children with learning disabilities, all of whom exhibit very jagged cognitive profiles—profiles that are extremely difficult to explain in terms of a unitary view of intelligence. We examine cognition in diverse animal species and in dramatically different cultures. Finally, we consider two kinds of psychological evidence: correlations among psychological tests of the sort yielded by a factor analysis of a test battery; and the results of efforts of skill training. When you train a person in skill A, for example, does that training transfer to skill B? So, for example, does training in mathematics enhance one's musical abilities, or vice versa?

Obviously, through looking at all these sources—information on development, on breakdowns, on special populations, and the like—we end up with a cornucopia of information. Optimally, we would perform a factor analysis, feeding all the data into a computer and noting the kinds of factors or intelligences that are extracted. Alas, this kind of material didn't exist in a form that is susceptible to computation, and so we had to perform a more subjective factor analysis. In truth, we simply studied the results as best we could, and tried to organize them in a way that made sense to us, and hopefully, to critical readers as well. My resulting list of seven intelligences is a preliminary attempt to organize this mass of information.

I want now to mention briefly the seven intelligences we have located, and to cite one or two examples of each intelligence. Linguistic intelligence is the kind of ability exhibited in its fullest form, perhaps, by poets. Logical-mathematical intelligence, as the name implies, is logical and mathematical ability, as well as scientific ability. Jean Piaget, the great developmental psychologist, thought he was studying *all* intelligence, but I believe he was studying the development of logical-mathematical intelligence. Although I name the linguistic and logical-mathematical intelligences first, it is not because I think they are the most important—in fact, I think all seven of the intelligences have equal claim to priority. In our society, however, we have put linguistic and logical-mathematical intelligences, figuratively speaking, on a pedestal. Much of our testing is based on this high valuation of verbal and mathematical skills. If you do well in language and logic, you will do well in IQ tests and SATs, and you may well get into a prestigious college, but whether you do well once you leave is probably going to depend as much on the extent to which you possess and use the other intelligences, and it is to those that I want to give equal attention.

Spatial intelligence is the ability to form a mental model of a spatial world and to be able to maneuver and operate using that model. Sailors, engineers, surgeons, sculptors, and painters, to name just a few examples, all have highly developed spatial intelligence. Musical intelligence is the fourth category of ability we have identified: Leonard Bernstein, Harvard Class of '39, has lots of it; Mozart, presumably, had even more. Bodily-kinesthetic intelligence is the ability to solve problems or to fashion products using one's whole body, or parts of the body. Dancers, athletes, surgeons, and craftspeople all exhibit highly developed bodily-kinesthetic intelligence.

Finally, I propose two forms of personal intelligence—not well understood, elusive to study, but immensely important. Interpersonal intelligence is the ability to understand other people: what motivates them, how they work, how to work cooperatively with them. Successful salespeople, politicians, teachers, clinicians, and religious leaders are all likely to be individuals with high degrees of interpersonal intelligence. Intrapersonal intelligence, a seventh kind of intelligence, is a correlative ability, turned inward. It is a capacity to form an accurate, veridical model of oneself and to be able to use that model to operate effectively in life.

These, then, are the seven intelligences that we have described in our research. This is a preliminary list, as I have said; obviously, each form of intelligence can be subdivided, or the list can be rearranged. The real point here is to make the case for the plurality of intellect. Also, we believe that individuals may differ in the particular intelligence profiles with which they are born, and that certainly they differ in the profiles they end up with. I think of the intelligences as raw, biological potentials, which can be seen in pure form only in individuals who are, in the technical sense, freaks. In almost everybody else the intelligences work together to solve problems, to yield various kinds of cultural endstates—vocations, avocations, and the like.

This is my theory of multiple intelligence in capsule form. In my view, the purpose of school should be to develop intelligences and to help people reach vocational and avocational goals that are appropriate to their particular spectrum of intelligences. People who are helped to do so, I believe, feel more engaged and competent, and therefore more inclined to serve the society in a constructive way.

These thoughts, and the critique of a universalistic view of mind with which I began, lead to the notion of an individual-centered school, one geared to optimal understanding and development of each student's cognitive profile. This vision stands in direct contrast to that of the uniform school that I described earlier.

The design of my ideal school of the future is based upon two assumptions. The first is that not all people have the same interests and abilities; not all of us learn in the same way. (And we now have the tools to begin to address these individual differences in school.) The second assumption is one that hurts: it is the assumption that nowadays no one person can learn everything there is to learn. We would all like, as Renaissance men and women, to know everything, or at least to believe in the potential of knowing everything, but that ideal clearly is not possible anymore. Choice is therefore inevitable, and one of the things that I want to argue is that the choices that we make for ourselves, and for the people who are under our charge, might as well be informed choices. An individual-centered school would be rich in assessment of individual abilities and proclivities. It would seek to match individuals not only to curricular areas, but also to particular ways of teaching those subjects. And after the first few grades, the school would also seek to match individuals with the various kinds of life and work options that are available in their culture.

I want to propose a new set of roles for educators that might make this vision a reality. First of all, we might have what I will call "assessment specialists." The job of these people would be to try to understand as sensitively as possible the abilities and interests of the students in a school. It would be very important, however, that the assessment specialists use "intelligence-fair" instruments. We want to be able to look specifically and directly at spatial abilities, at personal abilities, and the like, and not through the usual lenses of the linguistic and logical-mathematical intelligences. Up until now nearly all assessment has depended indirectly on measurement of those abilities; if students are not strong in those areas, their abilities in other areas may be obscured. Once we begin to try to assess other kinds of intelligences directly, I am confident that particular students will reveal strengths in quite different areas, and the notion of general brightness will disappear or become greatly attenuated.

In fact, I am now involved with colleagues in two collaborations through which we are attempting to determine what assessment might be like in the future. One such effort, undertaken with my colleague David Feldman, is taking place at a local preschool, with which we are working closely. We have richly equipped the school with materials that should engage the range of the students' intelligences, and in fact we call our effort "Project Spectrum." The children are allowed to gravitate naturally to a wide variety of games, puzzles, and other materials, and they can show us, through their play activities, what their particular combinations of interests and strengths are. At the conclusion of the school year, we present what we call a "spectrum profile" for each child to his or her parents and teachers. This is a description in plain English of a child's particular cognitive profile, together with some concrete suggestions of what might be done at home, in school, and in the wider community, to help that particular child to develop his or her interests and abilities.

Our second research collaboration involves the teaching of the arts and humanities to preadolescent and adolescent students. We are working with ETS, which does many things other than administer the SAT. In this project, named ARTS PROPEL, we are trying to develop new ways of figuring out the strengths of students in the junior and senior high school in the arts and humanities. We are agreed that, whatever use paper-and-pencil tests may have in other areas, they are not the optimal way to reveal students' latent abilities in the arts and humanities. In ARTS PROPEL, students are working instead in a much more molar way on large-scale projects, which will then be collected in portfolios for us to assess. It is my hope that a student profile based on such assessments might serve at least as an adjunct to standardized testing, and that perhaps it may eventually even serve as an alternative to testing.

In addition to the assessment specialist, the school of the future might have the "student curriculum broker." It would be his or her job to help match students' profiles, goals, and interests to particular curricula and to particular styles of learning. Incidentally, I think that the new interactive technologies offer considerable promise in this area: it will probably be much easier in the future for "brokers" to match individual students to ways of learning that prove comfortable for them.

There should also be, I think, a "school-community broker," who would match students to learning opportunities in the wider community. It would be this person's job to find situations in the community, particularly options not available in the school, for children who exhibit unusual cognitive profiles. I have in mind apprenticeships, mentorships, internships in organizations, "big brothers," "big sisters"—individuals and organizations with whom these students might work to secure a feeling for different kinds of vocational and avocational roles in the society. I am not worried about those youngsters who are good in everything. They're going to do just fine. I'm concerned about those who don't shine in the standardized tests, and who, therefore, tend to be written off as not having gifts of any kind. It seems to me that the school-community broker could spot these youngsters and find placements in the community that provide chances for them to shine.

There is ample room in this vision for teachers, as well, and also for master teachers. In my view, teachers would be freed to do what they are supposed to do, which is to teach their subject matter, in their preferred style of teaching. The job of master teacher would be very demanding. It would involve, first of all, supervising the novice teachers and guiding them, but the master teacher would also seek to ensure that the complex student-assessment-curriculum-community equation is balanced appropriately. If the equation is seriously unbalanced, master teachers would intervene and suggest ways to make things better.

Clearly, what I am describing is a tall order; it might even be called utopian. And there is a major risk to this program, of which I am well aware. That is the risk of premature billeting—of saying, "Well, Johnny is four, he seems to be musical, so we are going to send him to Juilliard and drop everything else." There is, however, nothing inherent in the approach that I have described that demands this early overdetermination—quite the contrary. It seems to me that early identification of strengths can be very helpful in indicating what kinds of experiences children might profit from, but early identification of weaknesses can be equally important. If a weakness is identified early, there is a chance to attend to it before it is too late, and to come up with alternative ways of teaching or of covering an important skill area.

We now have the technological and the human resources to implement such an individual-centered school. Achieving it is a question of will, including the will to withstand the current enormous pressures toward uniformity and unidimensional assessments. There are strong pressures now, which you read about every day in the national and local newspapers, to compare students, to compare teachers, states, even entire countries, using one dimension or criterion, a kind of a crypto-IQ assessment. Clearly, everything I have described today stands in direct opposition to that particular view of the world. Indeed that is my intent—to provide a ringing indictment of such one-track thinking.

I believe that in our society we suffer from three biases, which I have nicknamed "Westist," "Testist," and "Bestist." "Westist" involves putting certain Western cultural values, which date back to Socrates, on a pedestal. Logical thinking, for example, is important; rationality is important; but they are not the only virtues. "Testist" suggests a bias towards focusing upon those human abilities or approaches that are readily testable. If it can't be tested, it sometimes seems, it is not worth paying attention to. My feeling is that assessment can be much broader, much more humane than it is now, and that psychologists should spend less time ranking people and more time trying to help them.

"Bestist" is a not very veiled reference to a book by David Halberstam called *The Best and the Brightest*. Halberstam referred ironically to figures such as Harvard faculty members who were brought to Washington to help John F. Kennedy and in the process launched the Vietnam War. I think that any belief that all the answers to a given problem lie in one certain approach, such as logical-mathematical thinking, can be very dangerous. One of the leitmotifs of this symposium is the idea that current views of intellect need to be leavened with other points of view.

It is of the utmost importance that we recognize and nurture all of the varied human intelligences, and all of the combinations of intelligences. We are all so different largely because we all have different combinations of intelligences. If we recognize this, I think we will have at least a better chance of dealing appropriately with the many problems that we face in the world. If we can mobilize the spectrum of human abilities, not only will people feel better about themselves and more competent; it is even possible that they will also feel more engaged and more readily able to join with the rest of the world community in working for the broader good. Perhaps if we can mobilize the full range of human intelligences, and ally them to an ethical sense, we can help to increase the likelihood of our survival on this planet, and perhaps even contribute to our thriving.

Educating for a Moral Life

ROBERT COLES, *Harvard University*

How about this for a kind of intelligence, an important kind: for a parent to bring up a child, to feel love and affection, to struggle with impatience, to struggle with the sense of frustration and irritability, to yearn for things for the child and for oneself, to be faithful to the child, loyal to the child, faithful to the child's other parent. One might call this parental intelligence—human intelligence, caring and concern and devotion, devotion that allows for discipline and thoughtfulness and bad dreams and guilt at times, and for the sense of failure that one sometimes has to live down.

There is, I would argue, moral intelligence; and there is also immoral intelligence. There is mischievous intelligence, and wicked intelligence. This fall we will see published a history of the medical people who worked for the Third Reich—*The Nazi Doctors*. In that book, in a little footnote, we are reminded that in 1933 and 1934, some of the most prominent and distinguished intellectuals in Germany signed up with Hitler. They were doctors, and lawyers, and intellectuals; philosophers, psychoanalysts, psychologists, journalists, authors of books—high-IQ people, even in the seven categories just given us. These were people with credentials like mine and yours, university educations, and all sorts of dreams—some of them—yes, utopian. Think, too, of Rousseau, whose ideas we all call upon. Whoever looks at Rousseau's life, and all those children he fathered and abandoned? Rousseau created great theories, many books—and five or six children, strewn across France, whom he never cared enough to see for more than a day or two.

All the highly intelligent people I have just mentioned can be connected to evil, and mischief, and exploitation. So the issue is not only intelligence as a part of

Reform in Primary Mathematics Education: A Constructivist View

Constance Kamii, Barbara A. Lewis, and Sally Jones

Sometimes in danger of getting lost amidst the many theories of instruction in mathematics, children must be encouraged to do their own thinking rather than being taught shortcuts.

Mathematics education in the United States is well known to be in need of reform.[1] This need for improvement is clear from the beginning of the elementary grades, as we can see in a report of the National Assessment of Educational Progress:

> One would expect a majority of nine-year-olds . . . to have mastered basic mathematical operations . . ., as these skills are usually taught in elementary school. The fact that only twenty-one percent of the nine-year-olds attained this level in the 1986 assessment . . . suggests that reform in the mathematics curriculum may be warranted from the earliest grades.[2]

The research and theory of Jean Piaget have demonstrated that children acquire number concepts by *constructing them from the inside*, in interaction with the environment, rather than by *internalizing* them from the environment as traditional mathematics educators assume.[3] On the basis of this theory, called constructivism, we have been developing a way of "teaching" arithmetic in the primary grades.[4] One of the conclusions we have reached is that the teaching of rules, or algorithms, to get correct answers is harmful to children's learning of arithmetic. Our reasons for saying this are that (a) these rules go counter to children's natural ways of thinking, (b) algorithms "unteach" the little understanding children have of place value, thereby depriving them of opportunities to develop number sense, and (c) the history of computational procedures suggests that children would understand algorithms better if they were allowed to go through a constructive process similar to this evolution.

This article elaborates on these points and explains why we believe that children must be encouraged to do their own thinking rather than be taught shortcuts. Curriculum reform requires that we study children's process of learning and facilitate their process of construction instead of continuing to teach in ways that seem efficient for adults.

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Algorithms and Children's Natural Ways of Thinking

Two of us work at Hall-Kent School, a public school near Birmingham, Alabama, where a primary mathematics program is being developed on the basis of Piaget's theory. In this program teachers do not introduce any algorithms but, instead, encourage children to invent their own procedures for the basic operations. The following examples are typical of the procedures children invent and illustrate how their natural ways of thinking are in direct opposition to that of conventional algorithms (from the higher-order units to the ones in addition, subtraction, and multiplication, and from the lower-order to the higher-order units in division). These procedures are all invented in mental arithmetic, and children use writing only when a problem has so many steps that it is impossible to remember the results of previous steps (e.g., the division problem below).

$$\begin{array}{r} 16 \\ \underline{+17} \end{array}$$

10 + 10 = 20
6 + 7 = 13
20 + 10 = 30
30 + 3 = 33

10 + 10 = 20
7 + 3 = another ten
20 + 10 = 30
30 + 3 = 33

\+ + + + + + + + + +

$$\begin{array}{r} 43 \\ \underline{-15} \end{array}$$

40 - 10 = 30
3 - 5 = 2 below 0
30 - 2 = 28

40 - 10 = 30
30 - 5 = 25
25 + 3 = 28

\- - - - - - - - - -

$$\begin{array}{r} 13 \\ \underline{\times 4} \end{array}$$

4 x 10 = 40
4 x 3 = 12
40 + 12 = 52

x x x x x x x x x

$22 \overline{)275}$

22 + 22 + 22 + 22 . . .
until the total comes close to 275, or

10 x 22 = 220, and then proceeding by addition until the total comes close to 275

The order of steps in conventional algorithms is from right to left in addition, subtraction, and multiplication, and from left to right in division. Algorithms thus go counter to children's ways of thinking in each one of these operations and prevent them from using their own natural ability to think. Algorithms further hinder children's thinking in another way: By requiring them to write, algorithms focus children's attention on writing rather than on reasoning.

A Piagetian Task

Our emphasis on children's natural ways of thinking is based on Piaget's theory about the nature of logico-mathematical knowledge. The best way to explain this theory is with examples of children's reactions to a task.

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In this task, which was devised by Bärbel Inhelder and Jean Piaget, two identical glasses and about fifty wooden beads (or chips, beans, etc.) are used.[5] The child is given one of the glasses, and the interviewer takes the other glass. The interviewer then asks the child to drop a bead into his or her glass each time she drops one into her glass. After about five beads have thus been dropped into each glass with one-to-one correspondence, the adult says, "Let's stop now, and you watch what I am going to do." The interviewer then drops one bead into her glass and says to the child, "Let's get going again." The adult and the child drop about five more beads into each glass with one-to-one correspondence, until the adult says, "Let's stop." The following is what has happened so far:

Adult: 1+1+1+1+1+1+1+1+1+1+1
Child: 1+1+1+1+1 +1+1+1+1+1

The adult now asks, "Do we have the same amount, or do *you* have more, or do *I* have more?"

Four-year-olds usually reply that the two glasses have the same amount. When we ask, "How do you know that we have the same amount?" the children explain, "Because I can see that we have the same (amount)." (Some four-year-olds, however, reply that *they* have more, and when we ask them how they know that they have more, their explanation consists of only one word: "Because.")

The adult goes on to ask, "Do you remember how we dropped the beads?" and four-year-olds usually give all the empirical facts correctly, including the fact that only the adult put one bead into the glass at one point. In other words, four-year-olds remember all the empirical facts correctly and base their judgment of equality on the empirical appearance of the two quantities.

By age five or six (in kindergarten), however, most children deduce logically that the teacher has one more. When we ask these children how they know that the adult has one more, they invoke exactly the same empirical facts as the four-year-olds.

No one teaches five- and six-year-olds to give correct answers to these questions. Yet children all over the world become able to give correct answers by constructing numerical relationships through their own natural ability to think.

If a child says that the adult's glass has one more bead, the interviewer goes on to pose the next question: "If we continued to drop beads all day (or all night) in the same way (with one-to-one correspondence), do you think we will have the same number at the end, or will *you* have more, or will *I* have more?" Five- and six-year-olds divide themselves into two groups at this point. The more advanced group answers in the way that adults would; that is, there will *always* be one more in the interviewer's glass. The other group makes empirical statements such as "I don't know because we haven't done it yet" or "We don't have enough beads to keep going all day."

Children's responses in this task illustrate their construction of number concepts from within. No one teaches five- and six-year-olds to give correct answers to these questions. Yet children all over the world become able to give correct answers by constructing numerical relationships through their own natural ability to think. This construction from within can best be explained by reviewing the distinction Piaget made among three kinds of knowledge according to their ultimate sources and modes of structuring—physical knowledge, logico-mathematical knowledge, and social (conventional) knowledge.

Physical, Logico-Mathematical, and Social Knowledge

Physical knowledge is knowledge of objects in external reality. The color and weight of a bead are examples of physical properties that are *in* objects in external reality and that can be known empirically by observation.

Logico-mathematical knowledge, by contrast, consists of *relationships* created by each individual. For instance, when we are presented with a red bead and a blue one and think that they are *different*, this difference is an example of logico-mathematical knowledge. The beads are observable, but the *difference* between them is not. The difference exists neither *in* the red bead nor *in* the blue one, and

When children have not yet constructed the logico-mathematical relationship of numbers in their heads, all they can get from the experience is physical, empirical knowledge. This is why four-year-olds can remember the empirical facts of dropping all the beads except one with one-to-one correspondence.

if a person did not put the objects into this relationship, the difference would not exist for him or her. Other examples of relationships the individual can create between the same beads are "similar" and "two." Logico-mathematical knowledge is thus not empirical knowledge, since its source is in each individual's head. (However, we could not make relationships if there were no objects in the external world to put into relationship.)

The ultimate sources of social knowledge are conventions worked out by people. Examples of social knowledge are the fact that Christmas comes on December 25 and that a tree is called "tree."

The distinction among the three kinds of knowledge makes it possible to understand why most four-year-olds in the task described earlier say that the two glasses have the same amount. When children have not yet constructed the logico-mathematical relationship of numbers in their heads, all they can get from the experience is physical, empirical knowledge. This is why four-year-olds can remember the empirical facts of dropping all the beads except one with one-to-one correspondence. This one-to-one correspondence, however, is only empirical, and four-year-olds judge the quantity of beads also empirically. This is why they say that the two glasses have the same amount and explain, "I can *see* they have the same amount."

By age five or six, however, most children have constructed the logico-mathematical knowledge of numbers and can deduce from the same empirical facts that the teacher has one more bead. However, number concepts take many years to construct, and the child who has created them up to ten or fifteen does not necessarily have concepts of fifty, a hundred, or more.

Piaget's theory about the nature of logico-mathematical knowledge explains why we say that children have to construct this knowledge from within, through their own natural ability to think. Traditional mathematics educators are not aware of the difference between logico-mathematical and social knowledge and advocate the teaching of algorithms as if arithmetic were social knowledge. As a result, they unwittingly impose procedures that go counter to children's natural ways of thinking.

Algorithms, Number Sense, and Understanding of Place Value

The conventional algorithms for addition, subtraction, and multiplication are efficient because they allow us to treat every column as ones. These procedures are efficient for adults who already understand place value. For young children who are not sure of place value, however, these algorithms serve to reinforce their tendency to think about every digit as ones. Children who are made to use algorithms are thus deprived of opportunities to develop number sense. Below are three examples from research demonstrating that when children are encouraged to do their own thinking, they understand "tens and ones" better, have better number sense, and are superior in mental arithmetic.

Children's Explanation of "Carrying"

Individual interviews were conducted with eighty-five second graders to evaluate their understanding of "carrying" and of "tens and ones."[6] Thirty-nine of these children were in a traditional program in which algorithms were taught, and the other forty-six were in a constructivist program that encouraged children to invent their own procedures.

In the interview, each child was shown a card on which the following problem was written:

$$\begin{array}{r} 16 \\ \underline{+17} \end{array}$$

The interviewer asked the child to add the numbers mentally, give the answer, and then explain how he or she got the answer. Almost all the children in both groups gave the answer of 33. All the traditionally instructed children explained that they added the 6 and the 7 first. Almost all then said, in essence, "I put my 3 down here (pointing) and 1 up there, and 1 and 1 and 1 is 3; so I put 3 down here, and the answer is 33." By contrast, almost all the children in the constructivist group added the tens first and then the ones as described earlier.

The child was then given sixteen and seventeen chips for the two numbers and asked to explain, using the chips, how he or she arrived at the answer. The percentage of children who correctly explained "carrying" ten was twenty-three for the traditionally instructed group and eighty-three for the constructivist group ($p< .001$). The great majority of the traditionally instructed children "carried" one chip instead of ten, showing that they understood neither the algorithm nor "tens and ones" in this context.

Children's Handling of Misaligned Digits

In the final part of the interview, the child was given a sheet of paper on which the problem below was written.[7]

$$\begin{array}{r} 4 \\ 35 \\ \underline{+24} \end{array}$$

The interviewer asked the child to "read these numbers" and then to write the answer. When the child finished, the interviewer asked him or her to read the answer aloud and then inquired, "Does that sound right?"

The percentage of children who wrote "99" by mechanically following the rule of adding the columns was seventy-nine for the traditionally instructed group and eleven for the constructivist group ($p<.001$).

Children's Mental Arithmetic

Different groups of second graders were individually interviewed more recently and asked to solve the following problem (written horizontally) in their heads: 7 + 52 + 186. As can be seen in Table 1, the second graders who had not been taught any algorithms (class 3) did much better than those who had been taught these rules (class 1). Forty-five percent of class 3 gave the correct answer of 245, compared to twelve percent of class 1. Most children in class 1 used a right-to-left procedure. Those in class 3, on the other hand, all used a left-to-right procedure and said, for example, "180 + 50 = 230, 230 + 6 = 236, 236 + 2 = 238, 238 + 7 = 245." It is therefore not surprising that the errors found in class 3 were much more sensible than those in class 1. In class 3, most of the wrong answers were between 235 and 255. In class 1, by contrast, many children got small totals such as 29 and large ones ranging from 838 to 9308! (Those who got 29 or 30 did so by treating all the digits as ones, i.e., 7 + 5 + 2 + 1 + 8 + 6 = 29.) More than half of the children who had been taught algorithms thus demonstrated a lack of number sense.

The children in class 2 were in between, both in the instruction they had received and in the results. The teacher of class 2 did not teach the algorithm for addition but taught the one for subtraction and did not stop parents from teaching these rules.

When children are encouraged to do their own thinking, they develop number sense, and it becomes unnecessary to teach algorithms, number sense, mental arithmetic, and estimation separately. In an age of computers and calculators, number sense, mental arithmetic, and estimation are particularly important because children have to be able to sense an error when they hit a key unintentionally. The teaching of written algorithms was appropriate when all

Table 1

Second Graders' Answers to 7 + 52 + 186

	Class 1 *n = 17*	Class 2 *n = 19*	Class 3 *n = 20*
	9308		
	1000		
	989	989	
	986		
	938	938	
	906		
	838	810	
			617
		356	
	295		255
			246
245	(12%)	(26%)	(45%)
			243
		213	236
	200	213	235
	198	199	
		133	138
		125	
	30	114	
	29		
	29		
I can't do this.	(12%)	(21%)	(20%)

The teaching of written algorithms was appropriate when all we had was paper and pencil. In an age of calculators, however, ability to think and to estimate answers becomes much more important than ability to follow rules of written procedures.

we had was paper and pencil. In an age of calculators, however, ability to think and to estimate answers becomes much more important than ability to follow rules of written procedures.

The Constructive Process in the History of Computational Procedures

As an epistemologist, Piaget believed that the way to understand the nature of knowledge is to study the history of its construction by the human species as well as by individual children.[8] Just as he found many parallels between the evolution of physics, astronomy, etc., and the development of children's thinking in these areas, we found similarities between the history of computational techniques and the increasingly more efficient procedures invented by children at Hall-Kent School. As revealed in the following statement, today's algorithms were a very late achievement in human history: "It was not until 1600 that our modern Hindu-Arabic decimal system of numeration became generally accepted as the standard system of computations, replacing the use of Roman numerals."[9]

Until this surprisingly late date, most of our ancestors performed their computations with objects such as pebbles and counters, and with abacuses. Following is a sketch of how these objects were used before they were replaced by writing.

The Use of Objects

The Roman calculation board shown in Figure 1a consisted of a frame with parallel columns. The first column, on the right, was for ones, the second for tens, etc., and pebbles or counters were placed in each column to represent, for example, 4,365 as shown in this figure.

A variety of boards, tablets, and abacuses have been invented, but the basic principle of representing the base-ten system remained the same for centuries. Figure 1b shows 4,365 with a horizontal system that used the space between the lines to represent fives. "Five ones" is thus represented with one pebble above the line for ones. "Six tens" is shown with one pebble on the tens line and one above this line. This use of five as an intermediate higher-order unit

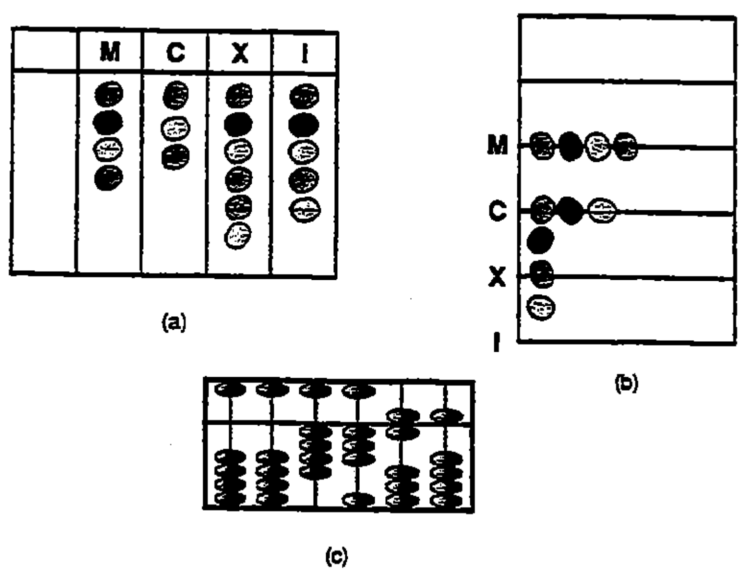

Fig. 1. Objects used as computational tools.

makes it easy to recognize six, seven, eight, and nine at a glance.

By putting ten beads that could be slid on a cord or a stick, our ancestors made the kind of abacuses that can still be seen today in many classrooms. The abacus disappeared from Europe by 1700 but is still being used in Asia. The most modern abacus being used in Japan today is shown in Figure 1c. The beads above the horizontal divider each stands for a five, and the ones below it each stands for a one. Figure 1c shows 4,365 represented by raising four ones in the thousands column, raising three ones in the hundreds column, lowering a five and raising a one in the tens column, and lowering a five in the ones column.

It is important for math educators to note that when our ancestors were using the abacus, they used writing to record only the *results* of the calculations carried out with the abacus. Groza states:

> Around 1100 the general public used Roman numerals and an abacus. Businessmen sat before a line abacus or counting table or "counter" (from which we obtain our present word *counter* as used in stores). Lines were ruled on the table [as shown in Figure 1b] to indicate the powers of 10 and loose counters were placed on these lines or between them and then moved as the calculations were performed.[10]

In Japan today, addition and subtraction are performed on the abacus by beginning with the highest-order unit and proceeding to the right, toward the ones. Instead of "carrying" and "borrowing," the abacus is used in the ways described below with respect to the following examples:

$$\begin{array}{r} 4{,}365 \\ \underline{+\,987} \end{array} \qquad \begin{array}{r} 4{,}365 \\ \underline{-\,987} \end{array}$$

To add 900, 100 is subtracted first and 1,000 is added. To add 80, 20 is subtracted first and 100 is added. To add 7, 3 is subtracted first and 10 is added. To subract 900, 1,000 is subtracted first and 100 is added. To subtract 80, 100 is subtracted first and 20 is added. To subtract 7, 10 is subtracted first and 3 is added. The reader must have noted striking similarities with the procedures invented by second graders at Hall-Kent School.

Compared to writing, physical actions on pebbles and beads are much more closely related to mental actions (thinking). In fact, these physical actions are direct extensions of mental actions. For example, pushing one bead up to add one is a direct extension of this mental action (whereas writing "+ 1" is not). The use of an abacus is also closely related to mental actions in another way: The person using an abacus has to know whether the place value is ones, tens, hundreds, etc. In a written algorithm, by contrast, once the columns have been aligned, every column can be treated as ones.

While the general public thus used counters and abacuses prior to 1600, a literate minority was inventing computational procedures that used writing. Much of this history has been lost, but a variety of procedures have nevertheless been preserved. We now turn to some examples, limiting ourselves to addition.

The Use of Writing

Five major procedures are described below: Bhaskara's method, the Hindu scratch method, and three others that include a method of "carrying."

1. Bhaskara's method (c. 1150).[11]

Groza describes the following way of adding 278 and 356:

Sum of the units	8 + 6 =	14	(14)
Sum of the tens	7 + 5 =	12•	(12)
Sum of the hundreds	2 + 3 =	5••	(5)
Sum of the sums		634	(634)

The column to the right in parentheses is the version given by Smith that does not use dots for zeros.[12]

Compared to writing, physical actions on pebbles and beads are much more closely related to mental actions (thinking). In fact, these physical actions are direct extensions of mental actions. For example, pushing one bead up to add one is a direct extension of this mental action (whereas writing "+ 1" is not).

Pearson describes the following similar but "left-handed" method.[13]

$$
\begin{array}{r}
278 \\
\underline{+356} \\
5 \\
12 \\
\underline{\quad 14} \\
634
\end{array}
$$

2. The Hindu scratch method.[14]

This method presented by Groza proceeds from left to right. The sum is written at the top in steps as illustrated below for the 278 + 356:

$$
\begin{array}{r}
\\
5 \\
\cancel{2}78 \\
\cancel{3}56
\end{array}
\longrightarrow
\begin{array}{r}
6 \\
\cancel{5}\cancel{2} \\
\cancel{2}\cancel{7}8 \\
\cancel{3}\cancel{5}6
\end{array}
\longrightarrow
\begin{array}{r}
63 \\
\cancel{5}\cancel{2}4 \\
\cancel{2}\cancel{7}\cancel{8} \\
\cancel{3}\cancel{5}\cancel{6}
\end{array}
$$

When this computation was done on a 'dust' board, the digits were erased as they were used instead of being scratched out. The successive phases of the same procedure resulted in progressively less writing as can be seen below:

$$
\begin{array}{r} 278 \\ 356 \end{array} \longrightarrow \begin{array}{r} 578 \\ 56 \end{array} \longrightarrow \begin{array}{r} 628 \\ 6 \end{array} \longrightarrow 634
$$

3. A left-to-right procedure described by Smith.[15]

$$
\begin{array}{r}
278 \\
\underline{+356} \\
\cancel{5}24 \\
63
\end{array}
$$

4. A column-by-column procedure described by Pearson.[16]

2	7	8
+3	5	6
5	12	14
6	3	4

5. Today's conventional algorithm of "carrying."

The following historical account of "carrying" by Smith (1925) helps us understand the conventional nature of this rule and the lateness of its invention:

> The expression "to carry" . . . probably dates from the time when a counter was actually carried on the line abacus to the space or line above, but it was not common in English works until the 17th century. Thus, we have Recorde (c. 1542) using "keepe in mynde," Baker (1568) saying "keepe the other in your minde," and Digges (1572) employing the same phraseology and also saying "keeping in memorie," and "keeping repose in memorie." The later popularity of the word "carry" in English is largely due to Hodder (3rd ed., 1664).[17]

While writing is removed from mental actions compared to physical actions on counters and abacuses, the old written procedures still allowed our ancestors to go through a careful process of reasoning step by step. In fact, similarities can be noted between our ancestors' written computational procedures and those invented by children at Hall-Kent School. Second graders at Hall-Kent School, for example, use writing to record mostly the *results* of their thinking. Our children also proceed from left to right as stated earlier.

We can see in light of the history sketched above that today's algorithms are the results of centuries of construction by the human species. The teaching of these algorithms is an attempt to transmit to children only the surface behaviors resulting from this historical evolution. Bypassing the constructive process may seem like an efficient way of teaching. However, children save time in the long run when they are allowed to invent their own shortcuts rather than being taught to mimick the final results of centuries of human inventions. When children are allowed to construct their own logico-mathematical knowledge, they invent increasingly more efficient procedures just as our ancestors did. By doing their own thinking and eventually accepting conventional algorithms of their own accord, children come to understand these rules and truly make them their own.

This article began by pointing out the need for reform in mathematics education. Attempts at reform must not aim at teaching adult algorithms "better." Instead, the time has come to take children's thinking seriously and to make fundamental changes. Instruction must enhance, rather than undermine, children's own construction of mathematics.

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How Do We Learn Our Lesson?

Taking students through the process

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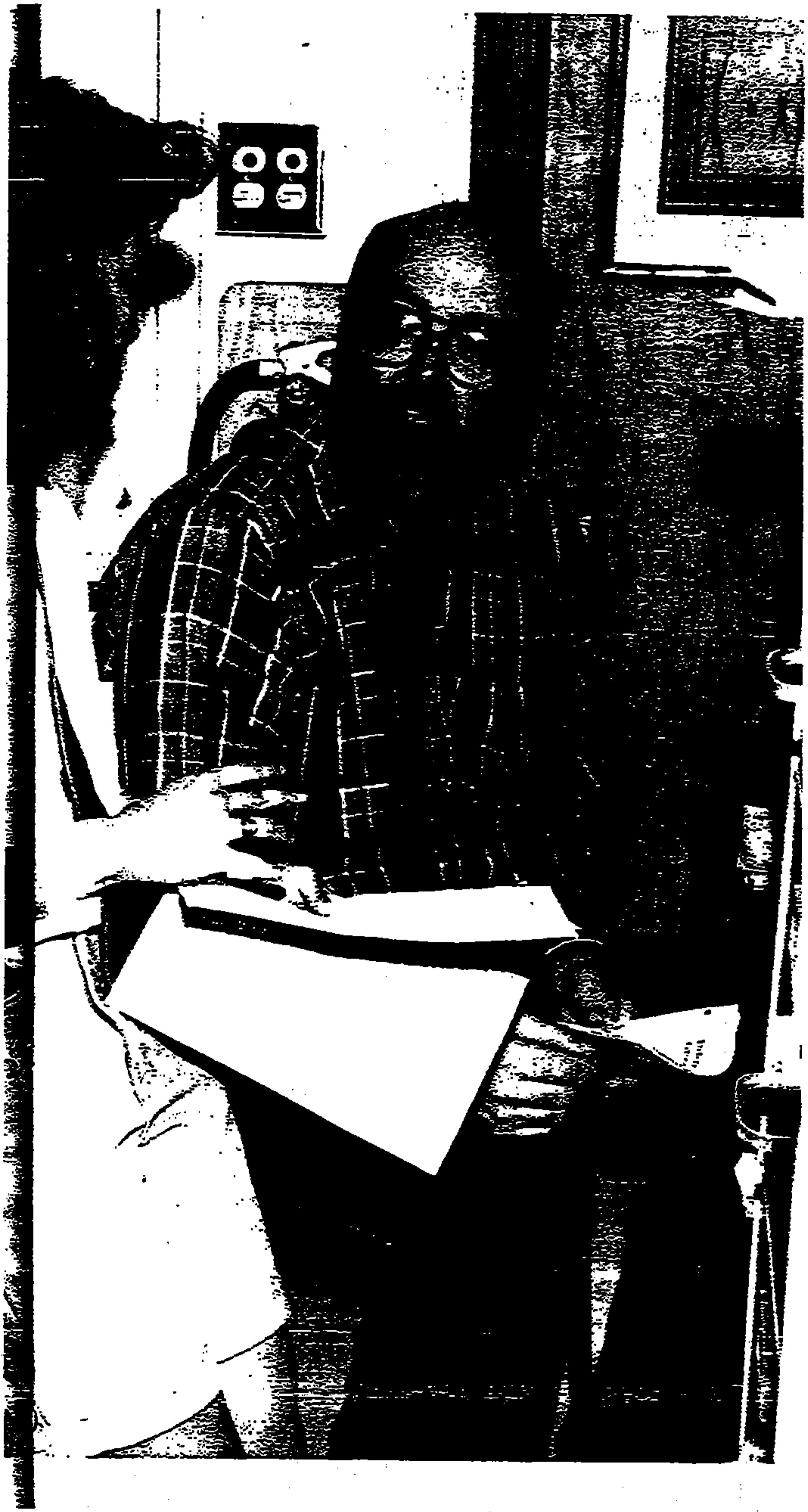


by Joseph D. Novak

The same year that E
Skinner's *The Behavio
Organisms* was publis
(1938), the president of
American Psycholog
Association told his c
leagues that more emphasis should
placed on meaning as a factor of learni
Since then, monumental studies by J
Piaget in Geneva and George Kelly in
United States have influenced educati
It was not until the 1960s, however, t
we began to understand how mean
affects learning.

David Ausubel was one of the f
researchers to study the connection
tween meaning and learning. In his 1
book, *Educational Psychology: A Cogni
View*, he wrote, "If I had to reduce al
educational psychology to just one p
ciple, I would say this: The most imp
tant single factor influencing learnin
what the learner already knows." This
been the guiding principle for my c
research groups. It is a simple idea,
has profound implications. The challe
How do we determine what a lea
already knows? Paper-and-pencil test
is a notoriously poor method. Pia
style clinical interviews can be very ef
tive, but require skill and are ti
consuming. Teachers need alternativ

One long-term study I was invol
with examined how children's conc
of the particle nature of matter chan
over 12 years of schooling. After revi
ing hundreds of tape records, we ide
fied three key factors:

1. Meaningful learning involves
assimilation of new concepts and pro
sitions into existing cognitive structu

2. Knowledge is organized hierar
cally in cognitive structure, and most
learning involves subsumption of c
cepts and propositions into existing h
archies; and

3. Knowledge acquired by rote learning will not be assimilated.

Rethinking the meaning of these ideas led our research group to try out various schemes for representing the structure of knowledge. The tool we developed, the concept map, is now familiar to most teachers. Figure 1 shows two examples of concept maps, drawn from a child in grade 2 and again in grade 12. These changes illustrate the key ideas this research documented:

1. Meaningful learning leads to progressively greater differentiation of the learner's knowledge structure;
2. Reconciling new meanings with old meanings can "correct" misconceptions; and
3. Rote learning is never integrated into a cognitive structure.

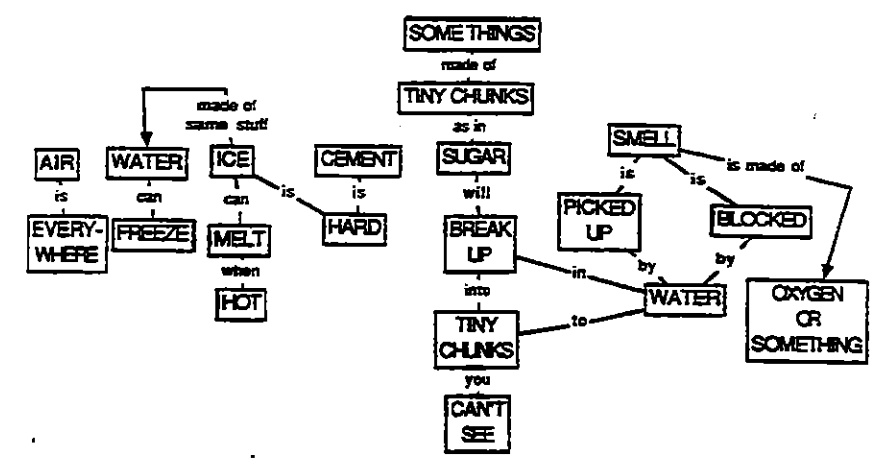
During the time we were developing the concept map approach, my colleague Bob Gowin was developing another sort of strategy to help students understand. His work is often called the Vee (or Vee Heuristic). Figure 2 shows the 12 elements of the Vee that we now use in our work (see Gowin's Vee in *TST*, October 1992).

DISCOVERING NEW MEANING

Meaning involves perceiving regularity. New knowledge is constructed when knowledge elements shown on the left side of the Vee are used to perceive new regularities or new relationships between regularities we already understand. We define a concept as a regularity that we can designate with a label. A principle is two or more concepts linked to form a statement about how something works.

For a young child, perception of regularity in the world is a genetic capacity, such as the ability to use language. By age three, most children can label several hundred concepts and use them to form thousands of propositions. This incredible accomplishment is normally achieved by discovery, not instruction. Language gives the child the ability to gain new

FIGURE 1. Concept maps.



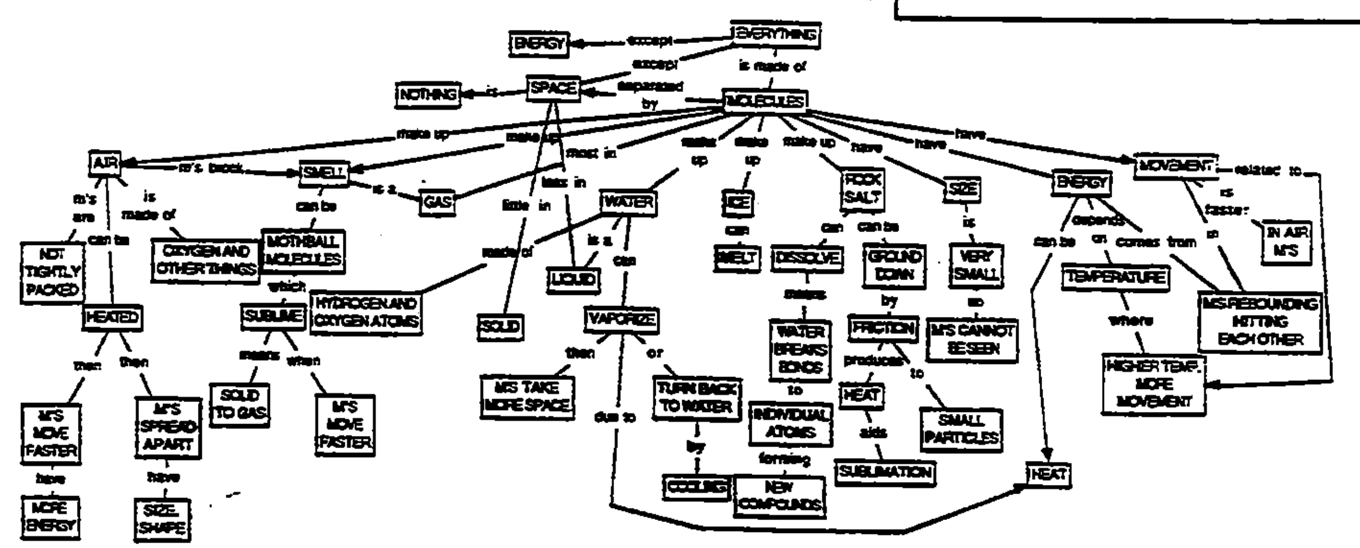
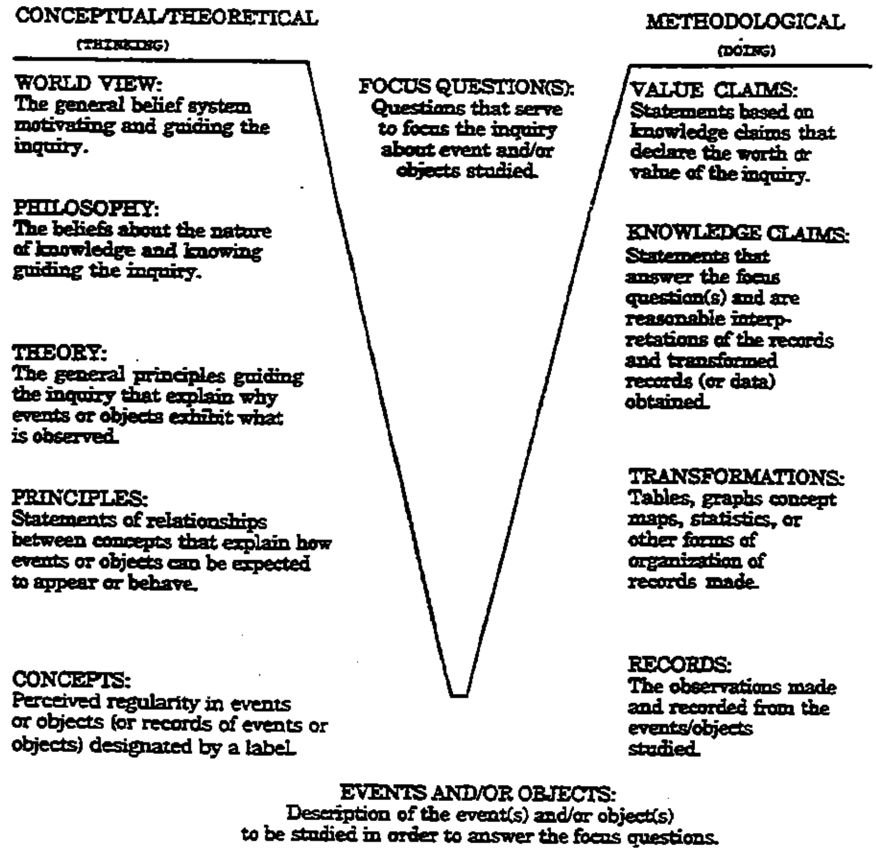


FIGURE 2. The 12 elements of the Vee.



Gowin's Vee showing epistemological elements which are involved in the construction or discription of new knowledge. All elements interact with one another in the process of constructing new knowledge or value claims, or in seeking understanding of these for any set of events and questions.

concepts and meanings by reception learning. This process proceeds until it is slowed in school by the barrage of rote learning to which most children are subjected. The unfortunate truth is that much school instruction inhibits student learning.

NO EMPTY SLATE

Another important understanding that has emerged during the past two decades is that human memory is not an "empty vessel" waiting to be filled. It is, instead, an interaction of three distinct memory systems (Figure 3).

In teaching science and mathematics, we are dealing with large bodies of subject matter that have the potential to reveal many relationships to students. But in discovering these relationships, students face the limitations of short-term memory. Even the most gifted can only handle about seven "chunks" of information at a time, and it is in this environment that *meaning making* must occur. The principal difference between a so-called genius and an average learner is that the genius has a capacity to use higher-order concepts in obtaining meaning from larger chunks of information.

Helping students acquire the ability to gain thinking skills has been the topic of many articles in recent years, including those in *The Science Teacher*. Many involve concept maps or Vee Heuristic diagrams because they are effective tools that help us organize the knowledge that is destined for long-term memory. They also help form mental scaffolds for students that help them learn how to think more critically and more creatively. Many recent studies indicate that educators need to empower learners by helping them organize and use carefully developed hierarchial knowledge structures.

CAN WE HELP STUDENTS LEARN HOW TO LEARN?

How can we help students learn how to take charge of their own meaning making? How can we help students understand that our minds are not storage bins into which we can pile knowledge indiscriminately? We must help our students understand that learning is not an activity that can be shared; it is the responsibility of the learner.

As Gowin points out, "Teachers do not cause learning; learners do." Teachers can help set the agenda for learning, however, and they can share the meanings they perceive with learners. They can also appraise learning to help the learner evaluate his or her understanding. And students need to know that understanding is never complete. It is an iterative process where the learner moves gradually toward greater understanding. Seeking understanding in any field is a life-long process. It is also an affective experience. It involves the pain and anxiety created by confusion, and the joy and excitement that we experience when we realize tha we have acquired new meaning.

My own interest in helping student learn how to learn gained impetus i 1974 after I had written *A Theory* *Education* and began using this book wit my graduate courses. A surprising num ber of students told me that, whil Ausubel's theories were interesting, th most valuable experience was learnin how to learn. After a few semesters, finally decided to organize a course on th topic.

My first effort in this direction bega in 1976. I used my own text, Fromm' *The Art of Loving*, and Harris' *I'm O. You're OK*. We drew concept maps and asked students to identify examples fro their college instruction that were co gruent with Ausubel's ideas. Most of the found many examples of bad teachin but only an occasional student describe coursework that illustrated good learning practice.

Many of the students who came to my course were looking for better grades. Dozens of "how to study" books were available, but none dealt with the topic of meaning making. I was probably naive in assuming that most students wanted to be empowered to enhance their own learning, but more mature students were very receptive to the idea of learning how to learn meaningfully.

The course, Learning How to Learn, was based on what would, today, be known as constructivism. One of the central ideas was that all meaning making is event-based. We used lectures and discussion as events and asked students to map sections of readings, prepare Vee diagrams, and plan and execute clinical interviews. I have found that the experience of interviewing others is the most powerful event that helps students understand and commit to meaning making.

Interviewing is a powerful teaching/learning tool. I would advise any teacher to include it in a science class. For example, teams of three to five students could select a topic currently being covered and collectively construct a concept map and Vee diagram to guide them in preparing interview questions. Topics that have values associated with them (What do students think about amniocentesis? Acid rain?) can be the most stimulating.

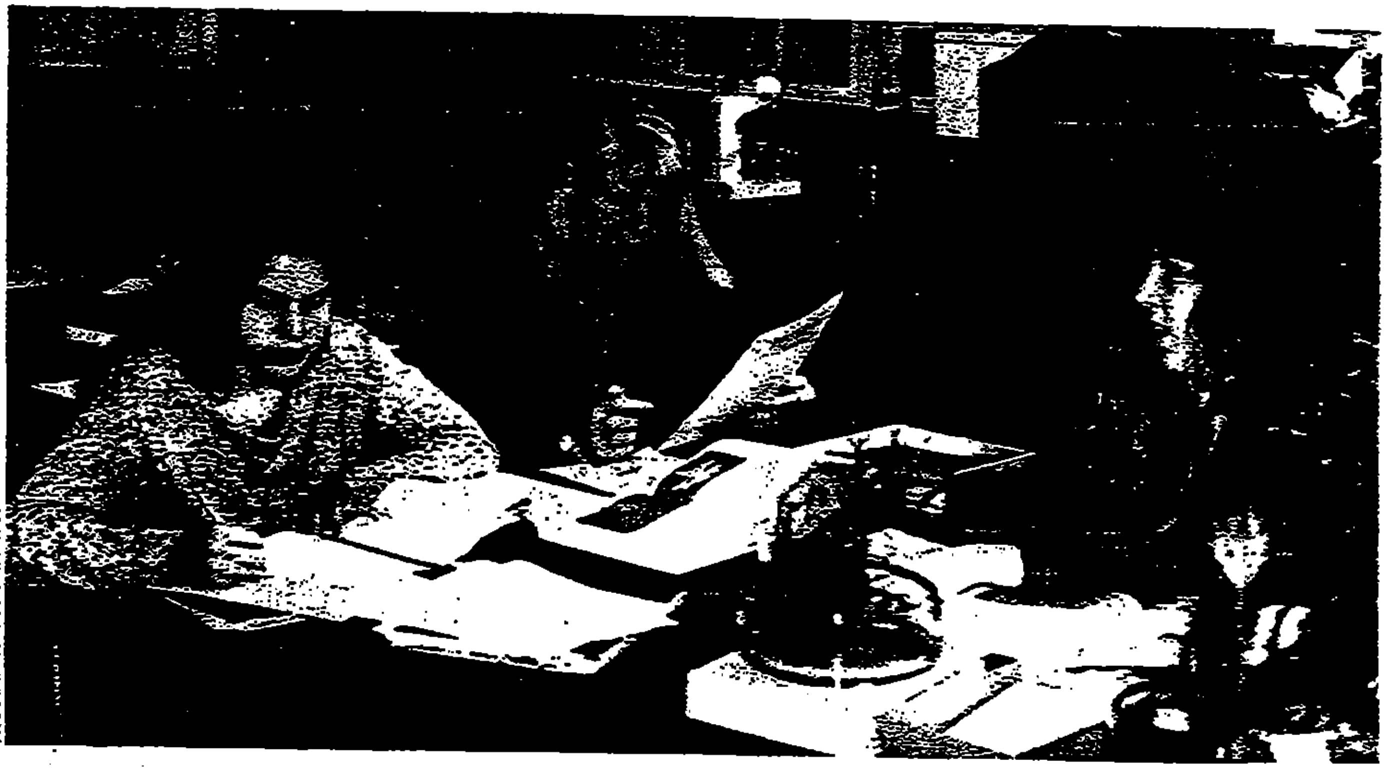
The experiences I have had with my college students have caused them to ask, "Why is schooling—and especially college schooling—so off the mark from what we know about empowering learners?" We often use one class period to discuss possible answers.

OBSTACLES TO HELPING STUDENTS LEARN

Every educational event has a learner, a teacher, a subject matter, and a social environment, according to Joseph Schwab. I would like to suggest a fifth element—evaluation. Pressure for accountability has focused so much of education on tests—however invalid—that they have become the sole concern of some teachers and their students.

Testing (as opposed to more valid authentic measures of learning) is one of the elements that prevent students from learning meaningfully. Teacher-made tests require specific, verbatim answers with little or no reference to meaning. They also contribute to the problem of motivating students; rote learning can have a relatively quick and easy payoff, but over the long term it is far less valuable than meaningful learning that can be applied to new situations.

By the end of college, most students understand that rote learning is bankrupt. Still, many of our seniors continue to memorize the answers to last year's exams because it pays off. There is a subtle immorality to this game, and both teach-



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ers and students are engaged in an intellectual fraud.

A second obstacle to meaningful learning is the curriculum. Too much subject matter is presented with too little time to explore concepts. There is little time to make subject matter conceptually transparent and, instead, it becomes conceptually opaque (see Clarify with Concept Maps, *TST*, October 1991).

EMPOWERING STUDENTS AND CITIZENS

Do we need "learning to learn" courses in schools? I do not think so. The growing number of thinking skills courses in schools may be counterproductive, since they burden an already crowded school curriculum and do little or nothing to change the way other courses are taught. However, I see great value in short courses for teachers at all levels to help them teach students how to learn more meaningfully.

At the same time, we need to address the social pressures that constrain rather than enhance a teacher's efforts to help students learn. New types of assessments (often involving concept maps or Vees) represent promising alternatives if they are already familiar to students. There is growing evidence that the use of instructional practices that encourage meaningful learning leads, in time, to improvement on standardized tests as well.

Money is always a factor in improving a system. But there is no evidence that it costs more to develop conceptually transparent instructional materials than materials that are opaque. It costs no more to emphasize meaning than the traditional strategies. It costs nothing to change minds about what is valuable.

In his best-selling book *Megatrends* (1982), Naisbitt suggested that our society will continue to move from institutional help to self help. Like the other trends in the book, this change will require a citizenry that is willing to seek out new solutions and ways of doing things. It is clear that only a schooling focused on meaningful learning can empower students to take charge of their future in constructive, creative ways.

It costs nothing to change minds about what is valuable.

It has been said that there is nothing so unstoppable as an idea whose time has come. Let us hope and work together to beat swords into plowshares and also to use resources to improve the quality of education.

I believe we know enough to take a quantum leap in schooling, especially in science and mathematics, that will help our students learn how to learn. This kind of education will lead to the human empowerment to take care of our Spaceship Earth, and each other.

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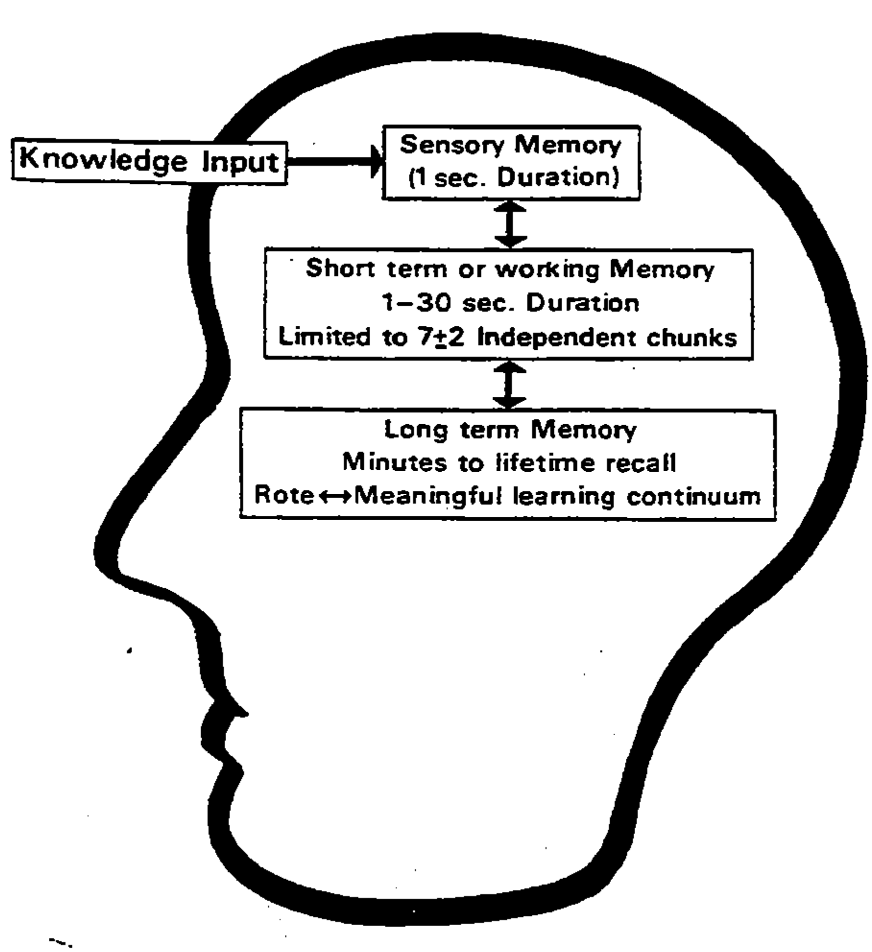
FIGURE 3. The three systems of human memory.



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Technologies for Lifelong Kindergarten

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Abstract

In kindergartens and early-elementary classrooms, manipulative materials (such as Cuisenaire Rods and Pattern Blocks) play an important role in children's learning, enabling children to explore mathematical and scientific concepts (such as number, shape, and size) through direct manipulation of physical objects. But as children grow older, and learn more advanced concepts, the educational focus shifts away from direct manipulation to more abstract formal methods. This paper discusses a new generation of computationally-enhanced manipulative materials, called "digital manipulatives," designed to fundamentally change this traditional progression. These new manipulatives (such as programmable building bricks and communicating beads) aim to enable children to continue to learn with a "kindergarten approach" even as they grow older—and also to enable young children to learn concepts (in particular, "systems concepts" such as feedback and emergence) that were previously considered "too advanced" for them.

Introduction

In 1837, Friedrich Froebel created the world's first kindergarten in Germany. Froebel's school was a important departure from previous educational institutions not only in the age of its students, but in its educational approach. Froebel had been deeply influenced by Swiss educator Johann Heinrich Pestalozzi, who argued that children need to learn through their senses and through physical activity. In Pestalozzi's words: "things before words, concrete before abstract" (Pestalozzi, 1803). In sharp contrast with previous schools, Froebel put physical objects and physical activity at the core of his kindergarten. He developed a set of 20 so-called "gifts"—objects such as balls, blocks, and sticks—for children to use in the kindergarten. Froebel carefully designed these gifts to help children recognize and appreciate common patterns and forms found in nature. Froebel's gifts and ideas were eventually distributed throughout the world, deeply influencing the development of generations of young children. Some historians argue that Froebel's gifts deeply influenced the course of 20th century art; indeed, Frank Lloyd Wright credited his boyhood experiences with Froebel's gifts as the foundation of his architecture (Brosterman, 1997).

Today's kindergartens are still full of physical objects and physical activity. Walk into a kindergarten, and you are likely to see a diverse collection of "manipulative materials" such as Cuisenaire Rods and Pattern Blocks. As children build and experiment with these manipulative materials, they develop deeper understandings of mathematical concepts such as number, size, and shape. As children play with Cuisenaire Rods, for example, they discover that one brown rod is the same length as two purple rods (or four red ones)—and, in the process, begin to develop frameworks for thinking about fractions and proportions.

But as children move on through elementary school and into secondary school, they have fewer interactions with manipulative materials. One reason: many important concepts are very difficult (if not impossible) to explore with traditional manipulative materials. For

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example, traditional manipulatives generally do not help children learn about the behavior of dynamic systems—how patterns arise through dynamic interactions among component parts. Such systems-related concepts are typically taught through more formal methods, involving abstract mathematical formalisms. Unfortunately, many students have difficulty with this approach, and thus never develop deep understandings of these concepts (Resnick, 1994; Sterman, 1994).

This paper discusses how the successful kindergarten strategy of learning-through-manipulation can be extended to a broader set of concepts. Specifically, it describes a new generation of manipulative materials that we have developed at the MIT Media Lab, in an explicit effort to expand the range of concepts that children (and adults) can explore through direct manipulation of physical objects. These new manipulatives, which we call "digital manipulatives," embed computational capabilities inside traditional children's toys—such as blocks, beads, and balls. These new technologies are in varying stages of development. Some of our new manipulatives have already been used extensively by children, in both schools and after-school settings; others are still in the early prototype stage.

The overarching goal of this research is two-fold. First, we hope that these digital manipulatives will enable children to continue to learn new concepts with a "kindergarten approach" as they progress through school—indeed, throughout their entire lives. At the same time, we hope that these new manipulatives will help young children learn concepts that were previously considered "too advanced" for them.

Guiding Principles for Digital Manipulatives

Our research on digital manipulatives is guided by three underlying principles:

1. Encourage Design Projects

In recent years, there has been a growing recognition of the educational value of *design projects*, in which students design and create external artifacts that they can share and discuss with others (e.g., Harel, 1991; Kafai, 1995; Lehrer, 1993; Papert, 1993; Resnick & Rusk, 1996; Soloway, Guzdial, & Hay, 1994). In some cases, students might create their own video games or animated stories; in other cases, their own kinetic sculptures; in still others, their own models and simulations. There are many reasons why design projects can provide rich opportunities for learning:

- Design activities engage children as *active participants*, giving them a greater sense of control over (and personal involvement in) the learning process, in contrast to traditional school activities in which teachers aim to "transmit" new information to the students.

- Design activities are often *interdisciplinary*, bringing together concepts from the arts, mathematics, and sciences.

- Design activities encourage *pluralistic thinking*, avoiding the right/wrong dichotomy prevalent in most school math and science activities, suggesting instead that multiple strategies and solutions are possible.

- Design activities provide a context for *reflection*. A child's constructions serve as external shadows of the child's internal mental models—providing an opportunity for children to reflect upon (and then revise and extend) their internal models of the world.

• Design activities encourage children to put themselves in the *minds of others*, since they need to think through how other people will understand and use their constructions.

This emphasis on design activities is part of a broader educational philosophy known as *constructionism* (Papert, 1993). Constructionism is based on two types of construction. Drawing on the *constructivist* theories of Jean Piaget (e.g., Piaget, 1972), it argues that learning is an active process, in which people actively construct knowledge from their experiences in the world. People don't *get* ideas; they *make* them. To this idea, constructionism adds the idea that people construct new knowledge with particular effectiveness when they are engaged in constructing personally-meaningful products. They might be constructing sand castles, LEGO machines, or computer programs. What's important is that they are engaged in creating something that is meaningful to themselves or to others around them.

Our research on digital manipulatives is part of a broader effort to develop new technological tools that help children work on design projects (and learn through their work on design projects). The traditional field of instructional design is of little help: it focuses on strategies and materials to help teachers instruct. Instead, we are interested in developing strategies and materials to help children construct. We call this effort "constructional design" (Resnick, 1996b; Resnick, Bruckman, & Martin, 1996). Constructional design is a type of meta-design: it involves the design of new tools and activities to support children in their own design activities. In short, constructional design involves designing for designers.

2. Leverage New Media

How we make sense of the world is deeply influenced by the tools and media at our disposal. If we are given new tools and media, not only can we accomplish new tasks, but we can begin to view the world in new ways. All too often, however, people cling onto the representations and ideas of the past, even in the presence of new media. Most applications of computers in education, for example, use computers in rather superficial ways. They take traditional classroom activities and simply reimplement them on the computer. The activities might be somewhat more engaging, and the computer might provide some additional feedback, but the activities themselves are not changed in fundamental ways.

Our research group aims to fundamentally rethink what children can and should learn, given the availability of new computational media. Many of the representations and activities used in today's schools were developed in the context of (and are most appropriate for) pencil-and-paper technology. We attempt to use computational media to create new representations and formulations of scientific knowledge—in order to make that knowledge accessible to more people (and at younger ages) than previously possible.

We have focused especially on helping children understand how systems behave and change—for example, the formation of a traffic jam on the highway, the coordinated movements of a bird flock, the fluctuations in a market economy. Why this domain? We believe that new computational media can provide significant leverage in rethinking the study of systems. For several centuries now, mathematicians and scientists have modeled system behaviors in terms of differential equations. Is that because differential equations are the best way to represent and describe these systems? Or is it because the common media of the past several centuries (paper and pencil) are well suited to manipulations of differential equations?

We developed StarLogo, a programmable modeling environment, to introduce a very different approach to the study of systems (Resnick, 1994, 1996a). To use StarLogo, children do not need to master advanced mathematical formalisms. Rather, they write simple rules for individual objects, then observe the group patterns that arise from the interactions among the objects. Our studies have shown that children, by using this approach, can learn important systems-related concepts (such as feedback and emergence) at much younger ages than previously possible. Our hope is that digital manipulatives will make these ideas accessible to even younger children, enabling children to explore these ideas through direct manipulation of familiar physical objects.

3. *Facilitate Personal Connections*

New technologies and new media can support new representations—which, in turn, can make certain concepts and ideas more salient for learners. But new *representations* are not enough. We must also consider *relationships*—that is, we need to consider how learners relate to the tools, activities, and representations in an educational setting.

An important goal is to connect new tools, activities, and representations to learners' interests, passions, and experiences. The point is not simply to make the activities more motivating—though that is important, since learners will work longer and harder on projects they care about. Learners also make deeper cognitive connections when they follow their interests. When activities involve objects and actions that are familiar and relevant, learners can leverage their previous knowledge, connecting new ideas to previously-constructed mental models (Resnick & Rusk, 1996; Schank, 1994).

In recent years, a growing number of researchers (e.g., Gilligan, 1982; Lave & Wenger, 1991) have argued that people form their strongest relationships with knowledge through "concrete" representations and activities—very different from the formal, abstract representations and approaches favored in traditional school curricula. This view calls into question the classic reading of Piaget (e.g., Piaget, 1972) which describes cognitive development as a one-way progression from concrete to formal or abstract ways of thinking. Some researchers have called for a "revaluation of the concrete" in the study and practice of mathematics and science, suggesting that "abstract reasoning" should not be viewed as more advanced than (or superior to) concrete manipulations (Turkle & Papert, 1990; Wilensky, 1991).

The computer can play an important role in this revaluation of the concrete; it "has the ability to make the abstract concrete" (Turkle & Papert, 1990). For example, the Logo turtle offers a much more concrete approach to learning geometry than traditional Euclidean approaches (Papert, 1980). Children can imagine themselves as the turtle as it draws out geometric shapes and patterns—a much more concrete experience than plotting Cartesian coordinates on graph paper.

Our research with digital manipulatives follows this tradition. But rather than creating new virtual objects (like the screen-based Logo turtle), we are embedding computation in traditional children's toys (like blocks, balls, and beads), which children can manipulate directly with their hands. Many computer-interface researchers are now exploring ways to add computation to everyday objects ranging from notepads and desktops to eyeglasses and shoes (e.g., Ishii & Ullmer, 1997; Weiser, 1991; Wellner, Mackay, & Gold, 1993). We focus on toys because of their role in "kid culture"; we hope to take advantage of children's deep familiarity with (and deep passion for) traditional childhood toys. Children grow up in constant interaction with toys and other physical objects; we want to leverage the intuitions and interests that children have developed from their lifelong interactions and experiences in the physical world.

LEGO/Logo

Our research on digital manipulatives grows out of our previous work on LEGO/Logo (Resnick & Ocko, 1991; Resnick, 1993). LEGO/Logo links the popular LEGO construction kit with the Logo programming language, integrating two different types of design activities. Children start by building machines out of LEGO pieces, using not only the traditional LEGO building bricks but newer pieces like gears, motors, and sensors. Then they connect their LEGO constructions to a computer and write computer programs (using a modified version of Logo) to control the actions of their constructions. For example, a child might build a LEGO house with lights, and program the lights to turn on and off at particular times. Then, the child might build a garage, and program the garage door to open whenever a car approached. Whereas traditional construction kits enable children to construct structures and mechanisms, LEGO/Logo goes further by enabling children to construct behaviors.

Logo itself was developed in the late 1960's as a programming language for children (Papert, 1980). In the early years, the most popular use of Logo involved a "floor turtle," a simple mechanical robot connected to the computer by a long "umbilical cord." With the proliferation of personal computers in the late 1970's, the Logo community shifted its focus to "screen turtles." Screen turtles are much faster and more accurate than floor turtles, and thus allow children to create and investigate more complex geometric effects.

In some ways, LEGO/Logo might seem like a throwback to the past, since it brings the turtle off the screen and back into the world. But LEGO/Logo differs from the early Logo floor turtles in two important ways. First, LEGO/Logo users are not given ready-made mechanical objects; they build their own machines before programming them. Second, children are not restricted to turtles. Elementary-school students have used LEGO/Logo to build and program a wide assortment of creative machines, including a programmable pop-up toaster, a "chocolate-carob factory" (inspired by the Willy Wonka children's stories), an automated amusement park, and a machine that sorts LEGO bricks according to their lengths. The LEGO company now sells a commercial version of LEGO/Logo. It is used in more than dozen countries, including more than 20,000 elementary and middle schools in the United States.

We developed LEGO/Logo with the goal of helping children learn both *through* and *about* design. We have found that children, through their design experiences with LEGO/Logo, can gain a richer understanding of certain mathematical and scientific concepts (Resnick, 1993). In some cases, they gain deeper understandings of concepts (such as friction and mechanical advantage) that are already in the elementary-school and middle-school curriculum. In other cases, they begin to develop understandings of concepts (such as feedback) that are traditionally not taught until the university level. Overall, we have found that children make deeper connections with mathematical and scientific concepts when they encounter—and *use*—the concepts in the context of personally-meaningful design projects.

At the same time, we have found that LEGO/Logo activities provide a rich opportunity for children to learn about the design process itself. As students work on LEGO/Logo projects, they learn important design heuristics and strategies (Resnick & Ocko, 1991). For example, they learn the value of modularity and iteration in the design process. Moreover, as students make use of the same design principles in two different media (for example, using modular design in both their LEGO machines and the Logo programs), they are more likely to recognize and appreciate that there are, in fact, deeper general principles involved.

The original LEGO/Logo technology has some clear limitations. In particular, LEGO/Logo constructions must be connected to a desktop computer with wires. These wires are a nuisance, especially when children create robotic "creatures." Wires often get tangled with other objects in the environment, get twisted in knots as the creature rotates, and restrict the overall range of the creature. Even more important, wires are a *conceptual* nuisance, limiting not only what children can build but also how they think about their constructions. It is difficult to think of a LEGO/Logo machine as an autonomous creature as long as it is attached by umbilical cord to a computer.

Programmable Bricks

We began our work on digital manipulatives by eliminating the wires of LEGO/Logo and embedding computation in LEGO bricks themselves—creating Programmable Bricks (Martin, 1994; Resnick, Martin, Sargent, & Silverman, 1996). Children can build Programmable Bricks directly into their LEGO constructions. To use a Programmable Brick, a child writes a Logo program on a personal computer, then downloads the program to the Programmable Brick (typically via infrared communication). After that, the child can take (or put) the Programmable Brick anywhere; the program remains stored in the Programmable Brick.

Each Programmable Brick has output ports for controlling motors and lights, and input ports for receiving information from sensors (e.g., light, touch, and temperature sensors). Programmable Bricks can also communicate with one another (and with other electronic devices) via infrared signals. Our first Programmable Bricks were roughly the size of a child's juice box. Our most recent Programmable Bricks, called Crickets, are smaller, lighter, and cheaper—roughly the size of children's Matchbox cars and action figures (figure 1).

As with LEGO/Logo, Programmable Bricks are intended to help children learn through and about design. But Programmable Bricks, by enabling children to embed computation directly into their constructions, significantly expand the space of design possibilities—and the space of learning possibilities. We have used Programmable Bricks with children in a variety of settings, including after-school clubs, weekend museum classes, and as part of the school-day curriculum. Hundreds of children have worked on projects with Programmable Bricks, and the LEGO company recently announced plans for a commercial version of Programmable Bricks.

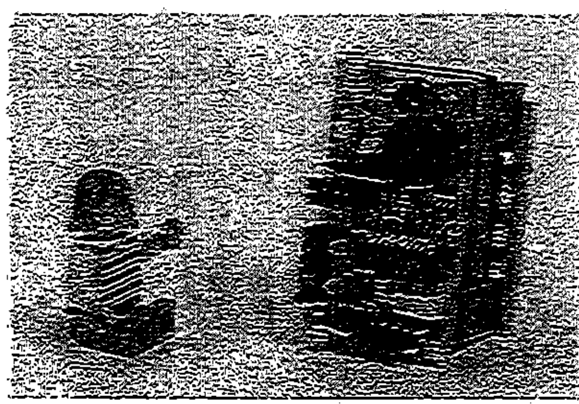

Figure 1:
A Cricket (LEGO figure shown for scale)

Robotic Creatures

Many Programmable Brick projects have revolved around the construction and programming of robotic creatures. In one elementary-school project (coordinated by Fred Martin), teachers and students decided on a theme of "Robotic Park." Each group of students selected an animal, researched the animal and its habitat, and then implemented LEGO models of the animals, using sensors, motors, lights, and Programmable Bricks.

One group of fifth-grade students, inspired by the movie Jurassic Park, created a LEGO dinosaur (figure 2) that was attracted to flashes of light from the headlights of a motorized Jeep (built by the same team). To make the dinosaur move toward the light, the students needed to understand basic ideas about feedback and control. The students wrote a program that caused the dinosaur to spin in a circle, looking for the Jeep's lights. When the reading from the dinosaur's light sensor crossed a certain threshold, the dinosaur started driving straight ahead. If the light sensor reading started to fall again, the dinosaur would start spinning again.

This algorithm (designed by the students themselves) is an example of a classic feedback strategy, typically not taught until university-level courses. But with the right tools, fifth graders were able to explore these ideas. The students also considered the similarities (and differences) between animals and machines. Were their LEGO creatures more like animals? Or more like machines? They compared their robots' sensors to animal senses, and they discussed whether real animals have "programs" like the ones they wrote for their robotic creatures (Resnick, Bruckman, & Martin, 1996). This type of activity and discussion is very different from what occurs in traditional elementary-school biology lessons. Traditional lessons focus on terminology and categorization; there is rarely discussion of animal behavior and almost never discussion of the processes underlying animal behavior.

Children have also used Programmable Bricks to create communities of robotic creatures that interact with one another. We have found that children, by teaching their creatures to communicate with one another, can learn some general principles about communication. When a child programs a creature to communicate with a second creature, the child must have a good model of what the second creature already "knows." For example, a 12-year-old boy programmed his LEGO creature to send a "dance" message to another creature (figure 3). But the second creature didn't know how to dance (that it, it hadn't been programmed with a dance procedure), so nothing will happen. The child saw two ways to

Figure 2: Fifth-grade students show off their LEGO dinosaur—including a knapsack to carry its Programmable Brick

fix this problem: to write a dance procedure for the second creature, or to program his first creature to send more detailed instructions (e.g., turn on your left motor for one second, then your right motor for one second, etc.). The general lesson: to communicate well, you must develop a model of your audience. This idea might seem obvious, but it is often ignored in interactions among people.

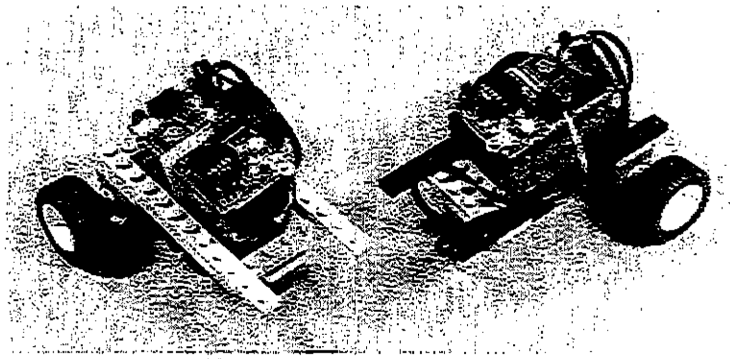

Figure 3:
Dancing creatures, with communicating Crickets

Build-It-Yourself Scientific Instruments

Recently, we have begun to use Programmable Bricks (in particular, the newer, smaller Crickets) in a new science-education initiative called Beyond Black Boxes (Resnick, Berg, Eisenberg, Turkle, & Martin, 1996). Many science-education researchers have argued that children should develop their own scientific investigations, rather than carrying out pre-scripted experiments, as is common in many classrooms (e.g., National Research Council, 1996). We go a step further, encouraging students to use Crickets to create their own scientific instruments to carry out their investigations.

We see several reasons to encourage children to design and build their own scientific instruments: (a) Students are more likely to feel a sense of personal investment in a scientific investigation if they design the scientific instruments themselves. (b) When students design their own scientific investigations, they will quite likely find that standard scientific instruments are not always well-suited to the tasks; by creating their own instruments, students are less constrained in their investigations. (c) Too often, students accept the readings of scientific instruments without question. When students design their own instruments (and thus understand the inner workings of the instruments), they should as a result develop a healthy skepticism about the readings. (d) To design their own scientific instruments, students need to figure out what things to measure and how to measure them. In the process (and in contrast to students simply performing "black box" measurements), they develop a deeper understanding of the scientific concepts underlying the investigation.

For example, Jenny, 11 years old, decided to use Crickets to build a new type of bird feeder. Jenny already had a conventional bird feeder in her backyard. But there was a problem: often, the birds would come while Jenny was away at school, so she didn't get to see the birds. Working at an after-school center (in a project organized by John Galinato and Claudia Urrea), Jenny decided to build a new bird feeder that takes a photograph of each bird that lands. She used a touch sensor, a Cricket, and a camera, and she built a special LEGO mechanism to depress the shutter of the camera (figure 4). She wrote a program that waited for a signal from the touch sensor (indicating that a bird had arrived) and then turned on a motor in the LEGO mechanism to depress the shutter of the camera. At the end of the day, the camera would have pictures of all of the birds that had visited the bird feeder. Jenny then ran an experiment to see if different types of bird food attracted different types of birds to the bird feeder. Children might have thought about these types of experiments in the past, but (before Programmable Bricks) they never had the appropriate materials to build the necessary instruments.

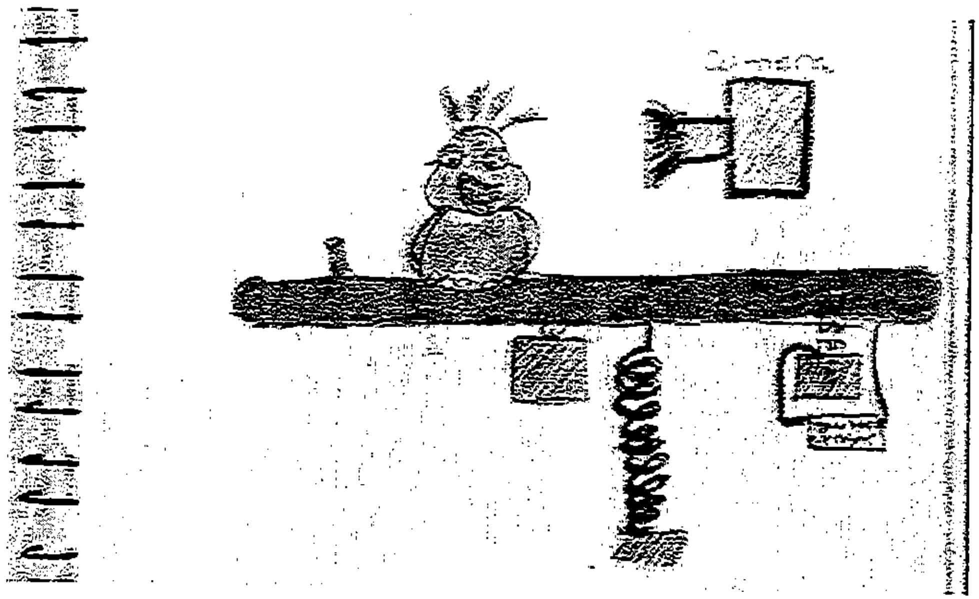

Figure 4: Jenny's drawing of her bird feeder

BitBalls

Programmable Bricks are our most fully developed digital manipulatives. But we have recently been exploring ways of adding computation to other childhood toys. In each case, our goal is to engage children in new ways of thinking, while also connecting to children's interests and passions.

The ball was the first of Froebel's kindergarten "gifts," and remains one of the most popular of all children's toys. In our BitBall project (organized by Kwin Kramer and Robbie Berg), we are embedding a Cricket inside of a transparent, rubbery ball (about the size of a baseball). The Cricket inside the BitBall includes an accelerometer and a set of colored light-emitting diodes (LEDs), so that the BitBall can "know" something about its motion and display some information (figure 5).

As with the Programmable Bricks, a child can write a program for the BitBall on a desktop computer, then download the program to the BitBall via infrared communication. The primary activity involves programming the BitBalls to turn on its LEDs based on its motion, as detected by the accelerometer. One student, for example, programmed a BitBall to flash its red light whenever it experiences a sharp acceleration or deceleration (i.e., whenever it is thrown or caught). Another student created a ball that "wants" to be played with: If the ball doesn't experience any sharp accelerations for a certain period of time, it begins flashing its lights in an effort to attract someone to play with it. We have found that children are quick to attribute intentionality to the BitBall (thinking that the BitBall "wants" to communicate a message), even when the BitBall is running the simplest of programs. When children program the BitBall themselves, they develop a better understanding of how seemingly-intentional behaviors can arise from just a few simple rules.

Since the BitBall (via its Cricket) can send and receive infrared signals, children can also program BitBalls to communicate with other electronic devices. For example, students have programmed the BitBall to send its acceleration data to a MIDI synthesizer in real time, in an effort to "hear the motion" of the ball (with, for example, acceleration mapped onto pitch).

BitBalls can also be used in scientific investigations. A BitBall can store its acceleration data and later upload the data to a desktop computer for analysis. For example, students have dropped a BitBall from the top of a building, then used the acceleration data to figure out the height of the building. Such investigations can lead to a deeper understanding of kinematics. One group of students (in this case, university students) threw a BitBall in the air and graphed the acceleration data in an effort to find the top of the trajectory. The students had the common misconception that the acceleration of a thrown object must change when the object is at its peak. In fact, they discovered that there was no change in acceleration while the ball is in flight, so it was impossible to determine the top of the trajectory from acceleration data alone. The students had previously studied gravity and acceleration in physics class, but they were not able to apply their classroom knowledge to this real-world context. We believe that experience with the BitBall will help students develop an understanding of acceleration that they can more easily transfer to new contexts.

Figure 5: A BitBall

It is important to note that the BitBall is significantly different from existing commercial toys with embedded electronics. Some companies, for example, sell yo-yos that turn on a light while they are moving. We believe that such toys are different from the BitBall along an important dimension. The light-up yo-yo is pre-programmed to do exactly one thing. It is a one-trick toy. The BitBall gives much greater flexibility and creative power to children. With the BitBall, children themselves decide how the toy should behave.

Digital Beads

In recent years, beads have become increasingly popular among children, especially young girls. There are entire stores with nothing but bins of beads of varying colors and sizes. Children string beads together to create colorful necklaces and bracelets.

With traditional beads, children create colorful but *static* patterns. Our Digital Beads (designed primarily by Kwin Kramer and Rick Borovoy) are intended to engage children in creating *dynamic* patterns. Each Digital Bead has a built-in microprocessor and LED, and it communicates with its neighboring beads by simple inductive coupling (figure 6). String beads together in different ways and you get different dynamic patterns of light. Some beads pass the light to the next bead along the string, other beads reflect the light back, still others "swallow" the light. Some beads pass the light with a particular probability. A slight change in the behavior or placement of one of the beads can lead to an entirely different pattern of activity in the overall collection.

Children can work with the beads at two different levels. For starters, they can string together pre-programmed beads (each with a fixed behavior), and observe the dynamic lighting patterns that arise from the interactions. More advanced users can write new programs and download them into the beads.

A string of Digital Beads can be viewed as a physical instantiation of a one-dimensional cellular automata (Toffoli & Margolus, 1987). In cellular automata, each cell changes its state based on the states of its neighboring cells. Cellular automata have proved to be a rich framework for exploring "emergent phenomena"; simple rules for each cell can lead to complex and unexpected large-scale structures. But cellular automata seem best suited as a tool for mathematicians and computer aficionados, not for children. The idea of writing "transition rules" for "cells" is not an idea that most children can relate to. Digital Beads allow children to explore ideas of decentralized systems and emergent phenomena in a more natural way, through the manipulation of physical objects.

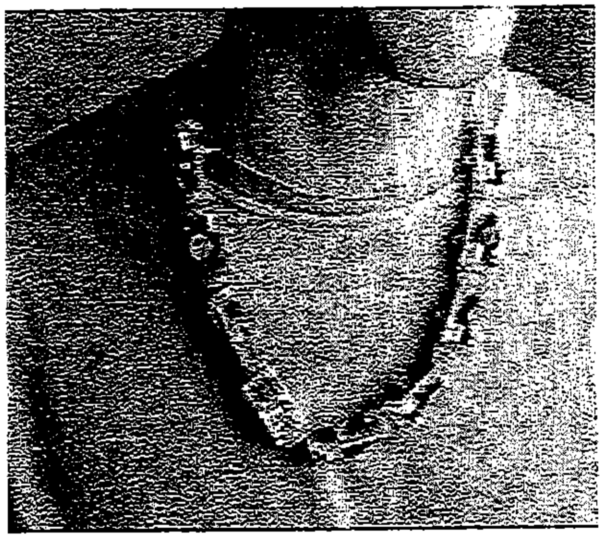

Figure 6: A necklace of Digital Beads

We believe that Digital Beads can also provide a meaningful and motivating context for children to begin thinking about probabilistic behaviors. Imagine a bead that passes the light to the next bead half of the time but reflects the light back to the previous bead the other half of the time. By stringing a set of these beads together, children can explore random-walk behaviors. What if you then add a bead that passes the light three-quarters of the time and reflects it just one-quarter of the time? How will that change the overall dynamic pattern? Most children (indeed, most people) have poor intuitions about such systems (Wilensky, 1993). Our hypothesis is that children who grow up playing with Digital Beads will develop much richer intuitions about probabilistic behaviors.

Digital Beads also provide a context for children to learn about "programming paradigms." There are two very different ways to think about programming the beads. Paradigm 1: Children can program the behaviors of the beads themselves, telling each bead to turn its light off or on based on its neighbors' lights. Paradigm 2: Children can program a "process" that jumps from bead to bead (e.g., turn on this bead's light for two seconds, then jump two beads down the string and turn on that light for three seconds). The important point is not for children to learn which of these paradigms is better (in fact, neither is inherently better). Rather, the important lesson is that there are often multiple approaches for describing behaviors, each with its own advantages.

Thinking Tags

Many children like to wear badges (such as a sheriff's badge) and buttons with slogans. Our Thinking Tags (designed primarily by Fred Martin, Rick Borovoy, Kwin Kramer, and Brian Silverman) are based on these traditional badges, but they have built-in electronics so that they can communicate with one another (via infrared communication)—and also change their displays based on those communications (figure 7).

We first developed the Thinking Tags for a conference (for adults) at the Media Laboratory. The Thinking Tags served as name tags, but each tag also contained information about the interests and opinions of its wearer. When two people met, their

Acknowledgments

The Digital Manipulatives research effort has been a group effort, with contributions from many people in my research group at the MIT Media Laboratory. Programmable Bricks and Crickets have been developed primarily by Fred Martin, Brian Silverman, Robbie Berg, and Bakhtiar Mikhak. The BitBalls have been developed primarily by Kwin Kramer, Robbie Berg, Fred Martin, and Brian Silverman. The Digital Beads have been developed primarily by Kwin Kramer and Rick Borovoy. The Thinking Tags have been developed primarily by Rick Borovoy, Fred Martin, Vanessa Colella, Brian Silverman, and Kwin Kramer. The work of Seymour Papert provided a foundation and inspiration for many of these projects. This research has been supported by generous grants from the LEGO Group, the National Science Foundation (grants 9358519-RED and CDA-9616444), and the MIT Media Laboratory's Things That Think, Digital Life, and Toys of Tomorrow consortia. Portions of this paper previously appeared in the proceedings of the CHI '98 conference (Resnick et al., 1998).

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TIMSS
UNITED STATES

Report No. 8

Press Statement by William H. Schmidt, U.S. TIMSS National Research Coordinator, Michigan State University

FACING THE CONSEQUENCES: USING TIMSS FOR A CLOSER LOOK AT UNITED STATES MATHEMATICS AND SCIENCE EDUCATION

Dordrecht: Kluwer Academic Publishers, in press

In the United States today we are faced with the consequences of an educational system which is an accretion of many choices and beliefs that have shaped our mathematics and science education. This report presents new analyses to provide a powerful and comprehensive characterization and perspective on the current state of US mathematics and science education based on data from the Third International Mathematics and Science Study (TIMSS). TIMSS is the most extensive and far reaching cross-national comparative study of education ever attempted. It included a comparison of official curricula, textbooks, teacher practices, and student achievements from many countries. (Since not all countries participated in all aspects of the study, the number of participating countries included in any one comparison ranges from 20 to 50.) From this broad ranging comparative evaluation of US mathematics and science education, the authors of the report suggest that two clear facts emerge. The first is that the children in the US receive their mathematics and science education through a fragmented system. Americans have chosen to distribute educational responsibilities so consistently to states and local districts that it is not meaningful to speak of a single US educational system but only of "educational systems." The second fact is that children in the US are not getting the science and mathematics education they deserve. As a consequence of commonly held educational beliefs and an accretion of a myriad of educational choices in many different places, they are not getting the education that would allow them to learn and perform to their greatest potential.

No single belief or choice may be identified as responsible for the current state of US mathematics and science education. In the first part of the report, some of the basic facts about classroom instruction are explored: how much time teachers spend on mathematics and science, what topics are taught and emphasized, as well as how and to whom these topics are taught. Among some of the more surprising results is the fact that the US is above average compared to other TIMSS countries in the number of hours it devotes to mathematics and science instruction (see Figure 1). In addition, in contrast to the practice of many high-scoring countries such as the Czech Republic, France, Hong Kong, Japan, and Korea which offered the same mathematics course to all students, nearly 75 percent of US thirteen-year old students were in schools offering two or more differently titled mathematics classes (see Figure 2). This type of tracking has a long history in the US, based on the belief that it is more efficient to teach students in homogenous groups according to their level of competence. The fact that other TIMSS countries did not track and yet surpassed the US in mean student achievement suggests that this common practice in US mathematics education must be questioned.

Consistent with the hypotheses presented in the earlier publication, *Characterizing Pedagogical Flow*, the TIMSS data found differences in the dominant patterns of instructional practices reported by teachers in different countries. For example, instruction in US eighth-grade mathematics classes was dominated by instructional approaches emphasizing seatwork and review – an approach not strongly represented among the teachers from some countries with high mean achievement. Approaches emphasizing instruction on new material were present in US mathematics lessons to the same or greater extent as in many TIMSS countries but not as much as in Hong Kong, Japan, Korea, and Singapore. Over half of US eighth-grade mathematics classrooms were dominated by review, seatwork, and homework. Since this differed markedly from the pattern in US eighth-grade sci-

Figure 1:
Mathematics Instruction Time in Schools Where All Students Study the Same Mathematics Course.

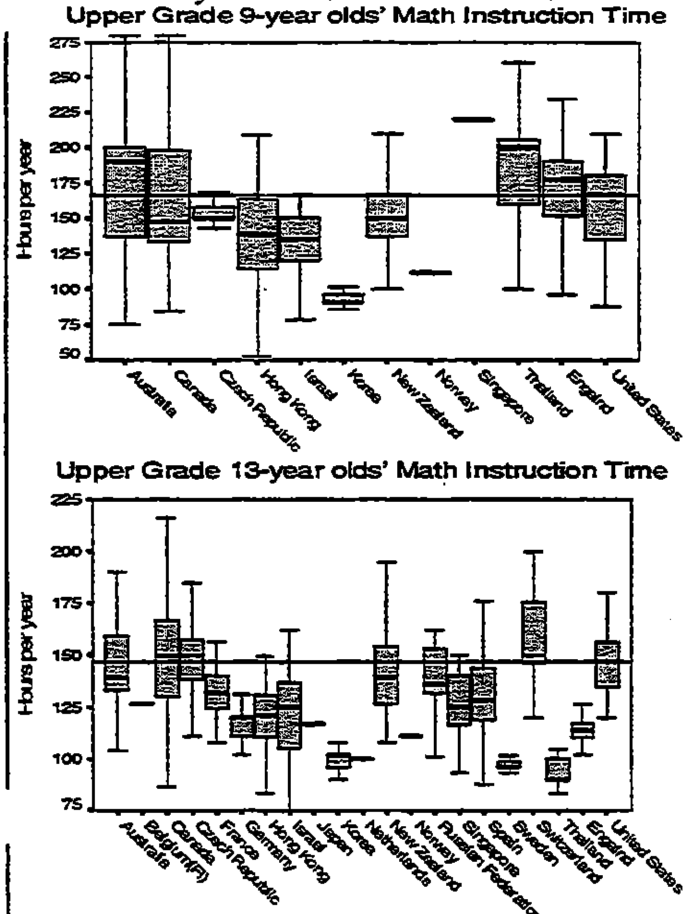
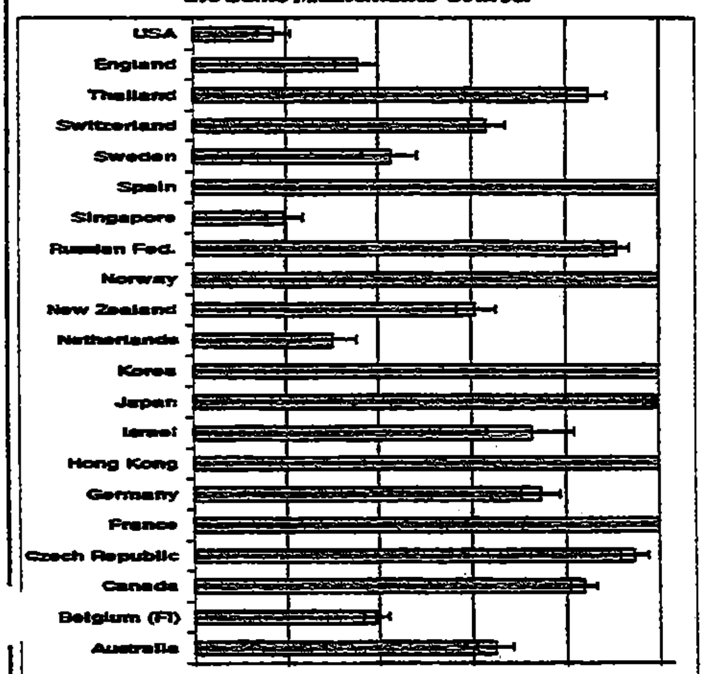


Figure 2:
Percentage of Students in Schools Where All Students Follow the Same Mathematics Course.



ence classrooms, this appears to be a characteristic of how school mathematics was conceived rather than a characteristic US instructional pattern. In many of these US mathematics classrooms, homework was frequently started in class. Only three other countries exhibited this practice in mathematics classes as did Singapore in their science classes.

The oft heard cry of "back to the basics" for US science and mathematics classes stems from the assumption that classrooms in this country have strayed far from their more traditional roots. This is an assumption unsupported by the TIMSS data. Rather, the empirical patterns observed reflect a widespread choice to focus on "basics." This concentration on basics in the US — both in instructional approaches and in curricula (documented more fully in *A Splintered Vision*) — must be questioned given the relatively disappointing and mediocre performance assessing students' learning as measured by the TIMSS tests. US instructional approaches and curricula, both in mathematics and science but especially for mathematics, are less in line with cross national commonalities than are the demanding curricula and classroom practices found in many high-achieving countries.

Students' beliefs and attitudes have the potential to either facilitate or inhibit learning. In this respect, US students did not appear to be especially unmotivated or ill-equipped learners in comparison to their counterparts in other countries. However, US seventh- and eighth-grade students reported studying less but being more optimistic about how well they were doing in mathematics and science than students in many other countries. In addition, a large proportion of these US students reported finding mathematics enjoyable but boring. The unchallenging nature of the curriculum for many and the routinized, undemanding teaching style many encounter may have contributed to this somewhat paradoxical finding. Furthermore, US students believed in the efficacy of hard work in learning mathematics and science more than their counterparts in many other countries.

The second section of the report moves beyond the global single-score reports of achievement to examine the results in greater detail, in ways that are more sensitive to variations in mathematics and science curricula. Contrary to the appearance with these global, single-score results, achievement does relate to differences in curricula. The inability to relate student achievement to educational experiences and curricula is largely a by-product of aggregating and scaling across different topics, contents, and skills. In these more detailed analyses considering more specific content areas of mathematics and science, one of the main findings is that no one country could do it all and do it well. Most countries demonstrated comparatively stronger performance in some specific content areas than in others. For example, Singapore's nine-year-olds, typically the top scorers, scored below those in the US in the area dealing with the geometry of shapes and positions. Australia's students score the highest in this area while ranking eleventh out of fifteen in the area of "rounding and estimating computations. US thirteen-year-olds scored near the bottom of the 22 countries listed in "Physical Changes," with only those in Hong Kong scoring lower, while US students scored second in "Life Cycles and Genetics" with only the students from the Czech Republic scoring higher (see Figure 3).

Examining the pattern of gains countries displayed across these more specific content topics makes the connection between curriculum and achievement even more clear. Countries generally varied more relative to other countries in their gains than in their comparative achievement level. Status, i.e., comparative achievement level, was determined by performance based on accumulated learning over many grades while gains were based on learning within a single grade. If status demonstrated the greater variability, one might suggest that differences were accidents of the measurement process and less likely to reflect anything other than the most marked curricular differences. However, the greater variability for gains (a measure more sensitive to curricular differences) suggests that variance among topics was related primarily to curriculum rather than other factors such as maturation and life experiences. Further evidence of the "mile wide, inch deep" US curriculum may be seen in the US's relatively flat gains profile compared to the notice-

Figure 3:
Science scores for specific content areas for upper grade thirteen-year-olds in selected countries compared to the US mean (national percent correct in each area)

Earth Features	
[illegible]	
Belgium (Fl)	61.1
Sweden	60.5
Thailand	59.7
Russian Federation	59.2
Norway	59.2
Japan	59.0
England	58.7
Switzerland	58.2
Netherlands	58.0
Australia	57.5
Germany	57.2
USA	57.1
Canada	56.6
Israel	56.1
Spain	55.9
New Zealand	55.9
International	55.4
France	55.1
Hong Kong	54.1

Earth Processes	
[illegible]	
Belgium (Fl)	65.4
Netherlands	62.5
Norway	62.3
USA	60.9
Russian Federation	60.8
Canada	60.6
Sweden	60.0
Korea	59.0
Japan	58.5
New Zealand	57.3
Czech Republic	57.2
Australia	56.7
Thailand	[illegible]
Switzerland	[illegible]
Spain	[illegible]
France	[illegible]
Israel	[illegible]
Germany	[illegible]
International	[illegible]
Hong Kong	[illegible]
Hungary	[illegible]

Earth in the Universe	
[illegible]	
Netherlands	67.5
Czech Republic	66.9
Japan	66.7
Thailand	66.0
Singapore	64.9
Switzerland	64.8
Korea	64.4
USA	63.3
Germany	62.8
Spain	62.8
Australia	62.7
Belgium (Fl)	61.8
New Zealand	61.7
Canada	61.2
England	59.0
Hungary	58.5
International	58.2
Hong Kong	58.0
Israel	56.2
Russian Federation	[illegible]
France	[illegible]

Diversity & Structure of Living Things	
[illegible]	
Sweden	67.7
Hungary	67.1
Australia	66.7
Germany	65.7
Russian Federation	65.7
England	64.5
USA	63.9
Canada	63.3
Belgium (Fl)	62.9
New Zealand	62.3
Spain	61.3
International	61.3
Switzerland	61.0
Israel	60.4
Norway	[illegible]
France	[illegible]

Life Processes & Functions	
[illegible]	
Thailand	63.0
Belgium (Fl)	62.9
Netherlands	60.7
Hungary	59.9
Russian Federation	59.4
England	59.3
Germany	58.1
USA	58.0
Australia	57.4
Canada	57.2
Israel	57.1
Hong Kong	56.3
New Zealand	56.1
Spain	55.9
Sweden	54.9
International	54.5
Switzerland	54.2
Norway	54.2
France	53.8

Life Cycles & Genetics	
Czech Republic	81.8
USA	81.2
England	80.4
Netherlands	79.3
Israel	79.0
Belgium (Fl)	78.9
Canada	78.4
Sweden	78.2
Norway	78.1
Korea	[illegible]
France	[illegible]
Russian Federation	[illegible]
Germany	[illegible]
Switzerland	[illegible]
Japan	[illegible]
New Zealand	[illegible]
Hungary	[illegible]
Australia	[illegible]
Spain	[illegible]
International	[illegible]
Singapore	[illegible]
Thailand	[illegible]
Hong Kong	[illegible]

Interactions of Living Things	
[illegible]	
Norway	59.9
Canada	58.2
Czech Republic	57.6
New Zealand	55.9
Netherlands	55.8
USA	54.3
Germany	52.9
Belgium (Fl)	52.9
Spain	52.9
Russian Federation	52.3
Sweden	52.1
International	51.0
Israel	50.2
Switzerland	49.8
Hong Kong	[illegible]
France	[illegible]

Human Biology & Health	
[illegible]	
Netherlands	71.2
Japan	69.4
Belgium (Fl)	69.3
Hungary	68.7
England	68.3
Israel	67.6
Germany	67.6
USA	66.8
Thailand	66.5
Australia	66.5
Korea	65.5
Canada	65.3
Sweden	63.9
New Zealand	63.7
Spain	63.2
Russian Federation	63.1
Norway	[illegible]
Switzerland	[illegible]
International	[illegible]
Hong Kong	[illegible]
France	[illegible]

Properties & Classification of Matter	
[illegible]	
Germany	54.9
Russian Federation	54.3
New Zealand	53.5
Israel	53.5
France	52.3
International	51.6
Switzerland	51.1
USA	49.9
Spain	49.6
Thailand	46.7

Structure of Matter	
[illegible]	
Czech Republic	54.2
Singapore	53.2
Spain	51.0
USA	48.2
Israel	44.7
Sweden	[illegible]
Korea	[illegible]
Japan	[illegible]
Hong Kong	[illegible]
International	[illegible]
Australia	[illegible]
England	[illegible]
Canada	[illegible]
Germany	[illegible]
New Zealand	[illegible]
Norway	[illegible]
Thailand	[illegible]
Netherlands	[illegible]
France	[illegible]
Switzerland	[illegible]
Belgium (Fl)	[illegible]

Energy & Physical Processes	
[illegible]	
Hungary	60.2
New Zealand	59.9
Canada	59.9
Hong Kong	59.5
Israel	59.5
Germany	59.3
Switzerland	58.7
Russian Federation	58.4
USA	57.1
Norway	56.6
Sweden	56.6
International	56.4
Thailand	55.3
Spain	55.2
France	54.6

Physical Changes	
[illegible]	
Russian Federation	57.0
Switzerland	54.0
Germany	53.6
Thailand	53.2
Spain	53.1
International	52.8
New Zealand	52.8
USA	49.1
Hong Kong	42.8

Chemical Changes	
[illegible]	
Korea	65.9
Hungary	65.4
Czech Republic	64.2
England	63.7
Japan	63.5
Australia	61.9
Russian Federation	61.8
USA	61.4
Germany	60.7
Israel	60.6
Canada	59.6
New Zealand	59.4
Hong Kong	58.2
Spain	58.1
Netherlands	57.6
Sweden	57.1
International	56.5
Belgium (Fl)	[illegible]
Switzerland	[illegible]
Norway	[illegible]
France	[illegible]
Thailand	[illegible]

Forces & Motion	
[illegible]	
Germany	66.9
New Zealand	65.6
Belgium (Fl)	65.2
France	63.8
Spain	62.6
Russian Federation	62.1
USA	61.3
International	61.2
Israel	54.9
Thailand	[illegible]

Science, Technology, & Society	
[illegible]	
Hong Kong	54.8
Canada	52.5
Switzerland	52.5
Norway	52.1
Czech Republic	51.9
Australia	51.5
Israel	51.3
International	47.9
USA	47.5
Germany	47.3
Spain	44.1
France	42.9
Russian Federation	40.4

Environmental & Resource Issues	
[illegible]	
Netherlands	65.1
Korea	62.7
Japan	61.7
Canada	61.5
New Zealand	61.4
USA	59.9
Belgium (Fl)	59.7
Czech Republic	59.1
Spain	58.6
Norway	58.2
Hong Kong	[illegible]
International	[illegible]
Sweden	[illegible]
Israel	[illegible]
Switzerland	[illegible]
Germany	[illegible]
Hungary	[illegible]
France	[illegible]
Russian Federation	[illegible]

Scientific Processes	
[illegible]	
Netherlands	65.2
France	62.2
Czech Republic	60.7
Australia	60.6
Japan	60.1
England	60.0
Canada	59.2
USA	58.9
Hungary	57.3
Hong Kong	57.2
Belgium (Fl)	56.9
New Zealand	56.7
Thailand	55.3
Germany	53.4
Israel	51.8
Switzerland	[illegible]
International	[illegible]
Sweden	[illegible]
Norway	[illegible]
Russian Federation	[illegible]
Spain	[illegible]

KEY
[illegible]
No Sig. Difference
Significantly Lower

able peaks for some topics seen in the gains profiles of nine- and thirteen-year olds in many other countries.

The TIMSS data further demonstrates that the cultural, ethnic, and racial heterogeneity of the US population cannot explain the variability in the mathematics and science results of US nine- and thirteen-year-olds. The patterns in US student achievement suggest that variations in mathematics and science achievement is not simply a matter of natural differences among persons since much of this can be linked to US curricular policies. Neither was the variability in US mathematics achievement particularly noteworthy compared to that in other TIMSS countries. Indeed, several of the high scoring countries such as Korea, Japan, Hong Kong, and the Czech Republic demonstrated more variability in their thirteen-year-olds' mathematics scores than what was found in the US.

The third part of the report summarizes new analyses and integrates them with previous results and conclusions to construct a comprehensive portrait of the structural characteristic of US mathematics and science educational practice. Some of these characteristics include:

- Official US mathematics and science curricula that were typically "a mile wide and an inch deep."
- Mathematics and science instruction in the middle grades that was highly repetitive and progressed little over the demands of earlier grades.
- Some students had access to educational possibilities in mathematics and science that were denied to others.

As much as the report seeks to build a case for the importance of curriculum in strong achievement, it would be a mistake to think that any one thing matters so much that it outweighs all other factors. There is no single factor that alone may solve all the difficulties in US mathematics and science education. Although many such panaceas have been proposed, the bottom line is that there are no magic bullets. Some of the "magic bullets" that are discussed more fully in the report as not supported by the TIMSS data include:

- Assigning more homework to produce greater achievement.
- Getting "back to the basics."
- Devoting more instructional time to mathematics and science.
- Put algebra earlier (e.g., in the eighth grade) or push more content down to earlier grades.
- Centralize curriculum and educational decision making.

The final section of the report includes a frank discussion of the lessons we can learn from TIMSS along with some consideration of the kinds of supplementary research that would be most helpful in understanding and improving US science and mathematics education.

Summary Prepared by Leland S. Cogan, Senior Research Associate, US National Research Center, Michigan State University.

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