Part 2

An Eight-Part Workshop Series for K-12 Teachers of Mathematics and Science
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About the Workshops

Series Overview

How many times have you wished you could just erase your students’ “wrong” ideas and help them relearn a topic? It’s tempting to think that a teacher’s job is simply to push those ideas aside and teach “right” ideas as replacements, but contemporary learning theories indicate that students are best able to rethink and exchange their ideas when they have tested them experimentally and shared their thinking with others. To assist children in this process, teachers must be armed with knowledge of how children construct their ideas and how they can help children make sense of their world. Children’s prior knowledge, like our own, is powerful and often persistent, and we have much to learn about it!

This series provides elementary and secondary teachers of mathematics and science the opportunity to hear from science and mathematics educators and some of the teachers, students, and parents who work with them. Each of the eight featured educators has studied some aspect of teaching and learning and has proposed modifications of classroom practices as a result of that research. *Looking at Learning Again...Part 2* encourages teachers to examine how theory and research into learning may inform their own classroom work. The series provides opportunities for teachers to discuss, critique, and apply the presented ideas with their colleagues. Finding ways to share ideas and to learn more about knowledge that is being newly generated is the core of this workshop series. In order to make teaching more effective, many different perspectives are brought together through videotapes, readings, discussions, and the Internet.

Series Structure

This exploration into learning theory will be carried out in a series of eight weekly workshops. Participants will be invited to reflect on their own beliefs about learning and discover the importance of looking at learning again and again throughout their teaching careers. Each workshop will feature a different educator and the theory that guides his or her practice. In addition to interviews with the featured educator, programs will include video clips of classrooms in which the theories are being practiced and discussions about the impact and the outcomes of such practices.

Each of the eight workshops will be two hours in length—a one-hour broadcast sandwiched between two 30-minute Site Investigations. These discussion/activity sessions will introduce and extend the featured learning theories and provide a forum for participants to discuss their application in the classroom. Weekly homework assignments will promote continued thinking between workshops and help participants document their progress throughout the series.

Workshop participants are encouraged to communicate and share ideas with teachers across the country on the *Looking at Learning Again...Part 2* interactive Web site (www.learner.org/channel/workshops/lala2). The collective information exchanged via cyberspace will enrich and extend the weekly workshops, and the opportunity to engage in discourse with a national community of teachers will greatly enhance the overall value of the series for all participants.
About the Workshops

Workshop Descriptions

Workshop 1. Dr. Philip Sadler—Behind the Design
Examine prototypical engineering designs and see how students modify these and learn physical science principles as they do so.

Workshop 2. Dr. Marta Civil—Mathematics: A Community Focus
Find out more about the “funds of knowledge” that children’s homes provide, and reflect on ways to connect children’s mathematics experiences at home and at school.

Workshop 3. Dr. Carne Barnett—Learning to Share Perspectives
Learn ways case discussion formats help teacher professional development groups understand children’s mathematical thinking. See teacher groups at work as well as children’s classroom use of mathematics cases.

Workshop 4. Dr. Peter Hewson—Conceptual Change
Discuss how students can be assisted in exchanging less powerful scientific conceptions for generally accepted science ideas.

Workshop 5. Dr. Robert Swartz—Infusing Critical and Creative Thinking
Consider how critical and creative thinking can be infused throughout the curriculum to help students better understand science concepts.

Workshop 6. Professor James Kaput—Algebra and Calculus: The Challenge
Find ways to embed algebra and calculus concepts into the curriculum much earlier in children’s school experience.

Workshop 7. Professor Herbert Ginsburg—Children’s Ways of Knowing
Explore the mathematics that children invent before they come to school and reflect on what this understanding could mean for mathematics curricula...even in high school.

Workshop 8. Dr. Wynne Harlen—Learning to Listen
Study students’ learning-in-progress and discuss ways to assess the development of their science content and process skills. Learn to provide students with the feedback needed to help them refine their ideas, and develop and test their science questions.
About the Workshops

Video Clip Descriptions

Workshop 1
Middle School, Everett, Massachusetts
Nancy Cianchetta challenges her students to design paper bridge trusses in order to look carefully at the concepts of tension and load.

Sharon Middle School, Sharon, Massachusetts
Jim Kaiser's students build understanding by experimenting with electromagnets that they construct.

Heights Elementary School, Sharon, Massachusetts
Diana Stiefbold's sixth-grade class works with chemical interactions by combining baking soda and vinegar and recording the results.

Workshop 2
Mary Louise Robins Elementary School, Tucson, Arizona
Leslie Kahn works with fourth- and fifth-grade students to develop their awareness of the mathematics in the games they play.

Liberty Elementary School, Tucson, Arizona
Juanita Diggins and her fifth-grade class are studying area. She has invited parents to observe the teaching and learning that are happening in the math class. Dr. Civil meets with the parents after the class to debrief and explore the math concepts.

Wakefield Middle School, Tucson, Arizona
This mothers' group has been meeting for more than a year to deepen their own understanding of mathematics, literacy, and school.

Sunnyside High School, Tucson, Arizona
Parents from around the city come together to learn more about the new methods of mathematics teaching and learning so that they can support their children's work at home.

Workshop 3
Maricopa Community College District Office, Tempe, Arizona
Alma Ramirez leads a discussion with a group of teachers as they analyze a case of teaching. They examine some of the pitfalls children fall into when manipulating fractions with different denominators.

Whittier Elementary School, Phoenix, Arizona
Maria Hernandez's sixth-grade class begins to use math cases by starting with familiar material.
About the Workshops

Video Clip Descriptions, cont’d.

V. H. Lassen Elementary School, Phoenix, Arizona
Jodi Griff’s fifth-grade class uses a math case to discuss whether they would rather have 6/10 or 4/5 of a dollar.

Park Elementary School, Hayward, California
Janna Winkowski’s second-grade students deepen their understanding of the equal sign by examining other children’s mathematical reasoning.

Treeview Bidwell Elementary School, Hayward, California
The first-graders in Leanna Baker’s class are constructing their understanding of the meaning of the equal sign.

Workshop 4
Day Middle School, Newton, Massachusetts
Robert Tai’s students share their ideas about what might happen in a frictionless universe and compare them with the science ideas they have been taught about friction and gravity.

Johnston Elementary School, Appleton, Wisconsin
Sara Bayer, a student teacher, interviews second-grade students to find out their ideas about the heart. She then goes on to plan class work.

Monona Grove High School, Madison, Wisconsin
Sue Johnson’s eleventh- and twelfth-grade genetics class test their ideas about genetic variation as they predict the wing shape and color of fruit flies.

Workshop 5
Brookfield Elementary School, Brookfield, Massachusetts
The children in Virginia Williams’ fourth-grade class are about to study the states of matter: solid, liquid, and gas. Virginia infuses creative thinking skills into the lesson by asking her students to brainstorm ways to melt an ice cube.

Millville Senior High School, Millville, New Jersey
Stephen Fischer uses graphic organizers with his tenth-grade students as they learn to categorize and identify organic molecules.

Freetown-Lakeville School District, Freetown, Massachusetts
Dr. Swartz works with teachers from the Freetown-Lakeville School District to explore how to incorporate creative and critical-thinking skills into their lessons.
About the Workshops

Video Clip Descriptions, cont’d.

Workshop 6
Doran Elementary School, Fall River, Massachusetts
June Soares encourages her third-grade class to record data and analyze patterns in many ways.

Doran Elementary School, Fall River, Massachusetts
June Soares presents mathematics problems that draw out algebraic reasoning with her third-grade students.

Central High School, Newark, New Jersey
Dr. Roberta Schorr from Rutgers University works with Ken Herskovits’ eleventh- and twelfth-grade students who are developing some sophisticated calculus ideas using computer simulations.

Fall River Teachers Workshop, Fall River, Massachusetts
Professor Kaput and his colleague Dr. Maria Blanton work with teachers who are introducing algebra concepts in their elementary mathematics lessons. The teachers discuss their students’ work and share ideas about ways to teach these concepts.

Workshop 7
Carillo Elementary School, Tucson, Arizona
Maria Lily Olivas’ fourth-grade students work on a valentine exchange problem. During the lesson, Ms. Olivas employs many strategies to learn about the children’s methods for solving the problem.

Corpus Christi School, New York, New York
Professor Herbert Ginsburg observes children in a Pre-K class during their free play with blocks and play dough and at the water table.

Corpus Christi School, New York, New York
Professor Ginsburg conducts clinical interviews with young children to discover their natural mathematics ideas.

Chatsworth Elementary School, Mamaroneck, New York
This research footage of Kay Kobe’s third-grade class shows how the students naturally develop their own methods for solving the multiplication problem 23 x 4.

Workshop 8
Clarendon School, San Francisco, California
Denise Ebisuzaki uses inquiry skills to assess her students’ comprehension of what materials conduct electricity. She uses the information she gathers during the lesson to plan her next steps.

Exploratorium Institute of Inquiry, San Francisco, California
Dr. Wynne Harlen conducts a professional development workshop with teachers and curriculum developers from around the country to assist them in the process of formative assessment.
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 theories of the guest featured in the next workshop; reading assignments can be found in the Appendix

Ongoing Activity
a reflective journal for keeping track of reactions to readings and videotapes, collecting and reflecting on data, and recording teaching ideas for yourself

Web site: http://www.learner.org/channel/workshops/lala2
a place to go for additional activities, resources, and discussion

Web Buddies: http://www.learner.org/channel/workshops/lala2/buddies
We encourage you to register to be matched with a Web Buddy, a colleague from another site who teaches at your grade level. Web Buddies will work together throughout the series on Ongoing Activities and other assignments and activities.

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.
About the Contributors

Featured Educators

Dr. Carne Barnett
Carne Barnett is a senior research associate at WestEd in Oakland, California, where she directs the Mathematics Case Methods Project. Teachers in this professional development project discuss cases about mathematics teaching dilemmas. Dr. Barnett’s own teaching experiences led to her interest in this pioneering work, which is patterned after methods used in other professions such as business and health. She has written numerous books for teachers and students and has been published in research journals. She was formerly a teacher educator at the University of California, Berkeley, and has conducted professional development across the United States and in Malaysia, Australia, and Saipan.

Dr. Marta Civil
Associate professor of mathematics at The University of Arizona, Marta Civil specializes in mathematics education, and in particular, in mathematics teacher education for grades K-8 and in cultural and social aspects in the teaching and learning of mathematics. She has presented her work at national and international meetings and has several published papers and articles. Currently, she leads three funded projects—one on bridging in-school and out-of-school mathematics, another on parental involvement in mathematics, and a third on gender equity in science, technology, engineering, and mathematics. Most of her work has focused on working-class Latino communities.

Professor Herbert Ginsburg
Professor Herbert Ginsburg holds the Jacob H. Schiff Chair at Teachers College, Columbia University, where he is professor of psychology and education. For the past 30 years, he has conducted research on cognitive development—particularly the development of children’s mathematical thinking—both within the U.S. and in various cultures around the world. He has used the knowledge gained from research to develop several kinds of educational applications and has created video workshops to enhance teachers’ understanding of their children’s learning of mathematics. He has also contributed to the Silver Burdett & Ginn mathematics textbook series, developed tests of mathematical thinking, and explored how the “clinical interview” method for assessing children’s mathematical knowledge can be used by teachers in their classrooms. Currently, he is engaged in research on young children’s mathematical competence and is developing a new mathematics curriculum for 4- and 5-year-old children.

Dr. Wynne Harlen
Wynne Harlen worked as a professor of education at universities in Reading, London, and Liverpool before being appointed as the director of the Scottish Council for Research in Education. She has spent her working life in research, development, and evaluation of children’s learning in science. Her particular concerns are to help teachers help children learn with understanding and, through the use of scientific process skills, to develop concepts, attitudes, and values that promote scientific literacy, lifelong learning, and respect for the environment. Her 16 books include Taking the Plunge, The Teaching of Science in Primary Schools, and the recently published third edition of Teaching, Learning and Assessing Science.
About the Contributors

Featured Educators, cont’d.

**Dr. Peter Hewson**

Professor of science education at the University of Wisconsin-Madison, Peter Hewson studies how students learn science, how teachers teach science, and how people become teachers of science. In doing so, he uses ideas about conceptual change as a common theme in understanding the complexity of practice in classrooms with diverse human beings. He is a co-author of *Designing Professional Development for Teachers of Science and Mathematics*, published in 1998, and is currently working on teacher professional development in a joint collaboration between the U.S. and South Africa.

**Professor James J. Kaput**

Chancellor professor in the Department of Mathematics at the University of Massachusetts, Dartmouth, James Kaput specializes in elementary students’ development of algebraic reasoning and the development of affordable technologies for mathematics education. Dr. Kaput has recently turned his attention to the massive implementation of technology-based innovations to democratize access to powerful mathematics, especially among disadvantaged populations. He is on the editorial board of six mathematics education journals and is a founding co-editor of a new series of volumes sponsored by the Conference Board of the Mathematical Sciences on Research in Collegiate Mathematics Education.

**Dr. Philip M. Sadler**

Philip Sadler is an assistant professor of education at the Harvard Graduate School of Education, F. W. Wright Lecturer on Navigation in the Department of Astronomy, and director of the Science Education Department at the Harvard-Smithsonian Center for Astrophysics (CfA). He joined the CfA in 1985 as director of Project STAR and is largely responsible for building the organization that is in place today. He received his B.S. in physics from Massachusetts Institute of Technology in 1973 and, from Harvard University, received both an M.A. in education in 1974 and an Ed.D. in 1992.

**Dr. Robert J. Swartz**

Robert Swartz received his Ph.D. in philosophy from Harvard University. He is a faculty member at the University of Massachusetts at Boston and the director of the National Center for Teaching Thinking. Through the Center, he provides staff development to educators across the country on infusing critical and creative thinking into content instruction. He has authored numerous articles and books on critical thinking and has acted as a thinking-skills testing consultant for the National Assessment of Educational Progress.
About the Contributors

Content Advisors

Anita Greenwood, Ed.D.
Anita Greenwood has worked in science education for 23 years, first as a teacher in the United Kingdom and now at the Graduate School of Education, University of Massachusetts Lowell. She conducts numerous science workshops for K-12 teachers and works with preservice science teachers and doctoral students. Her background is in the biological sciences. She can be seen in Shedding Light on Science, a science content workshop series for elementary teachers.

Rebecca Corwin, Ed.D.
Rebecca Corwin taught fifth grade for 10 years. She is currently professor of education at Lesley College in Cambridge, Massachusetts, and works with her graduate students in an elementary school in Boston, bringing their practical and theoretical knowledge together as they learn to be teachers. She has written a number of books for teachers, including the Used Numbers series about statistics and data analysis, and has produced a series of mathematics professional development videotapes and an accompanying book, entitled Talking Mathematics.

Jayne Ogata
Jayne Ogata has worked for the past 10 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 through workshops and media.
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 may 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 each week. In fact, we recommend that participants rotate the role of facilitator on a weekly basis.

Review the Site Investigations and bring the necessary materials.

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 more productive if you and your colleagues come to the workshops prepared for the discussions. The weekly readings and homework assignments provide for productive and useful workshop discussions. A few of the Site Investigations require special materials. The facilitator should be responsible for bringing these when necessary.

Note: Special materials and a reading assignment are required for Workshop 1. Prior to Workshop 1, please read the article, “About Project DESIGNS: Project DESIGNS Goals That Cross All Modules,” by Philip Sadler, which can be found in the Appendix. See page 18, Materials Needed, for the special materials required for the Getting Ready activity.

Keep an eye on the time.

Thirty minutes can go by very quickly, and it is easy to lose track of the time. 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 your 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

Reflective Journal

Overview

A critical part of taking steps toward change is representing learning along the way. This is a deliberate process that calls for reflecting upon your own understandings before, during, and after key experiences, and documenting how these understandings change. While there are numerous ways to represent learning, we suggest using a journal to keep track of your own ideas, reactions, and thoughts. One way to organize the journal would be to keep separate sections for:

• notes on readings;
• data you collect and analyze;
• brainstorming lists or concept maps you prepare for various sessions; and
• your reactions to readings, discussions, and presentations.

You may also organize your journal by session number. Whatever you do, use it to reflect, record, and capture your thoughts about this series.

There will be preparatory readings and/or activities for each session, and having a place to keep those will be extremely helpful. The group meetings will be more productive if you are well prepared for the introductory discussions.
Materials Needed

Workshop Discussions

WORKSHOP 1: Behind the Design
• several single sheets of notebook paper with holes for a standard 3-ring binder
• *if possible,* self-adhesive hole reinforcements for both sides of the paper
• hole punch
• 2 pushpins
• scissors
• large paper clip (bent into an S shape)
• any object weighing about 750g (2 lbs.)

WORKSHOP 3: Learning to Share Perspectives
• 16 beans or other discrete objects (thumbtacks, erasers, small blocks)

WORKSHOP 8: Learning to Listen
• examples of student work
Workshop 1

Behind the Design

DESCRIPTION
Young children are natural designers and builders, but if their interest is not fostered, it may wane as they move through the grades. This workshop will focus on the use of simple design prototypes that children are asked to improve upon in order to meet a particular challenge. You will see these design challenges in action in middle school classrooms, as well as hear teachers discuss their experiences using designs with their students.

DR. PHILIP M. SADLER
Philip Sadler is an assistant professor of education at the Harvard Graduate School of Education, F. W. Wright Lecturer on Navigation in the Department of Astronomy, and director of the Science Education Department at the Harvard-Smithsonian Center for Astrophysics (CfA). He joined the CfA in 1985 as director of Project STAR and is largely responsible for building the organization that is in place today. He received his B.S. in physics from Massachusetts Institute of Technology in 1973 and, from Harvard University, received both an M.A. in education in 1974 and an Ed.D. in 1992.
Bridge Challenge
Suspend a weight from a simple bridge for 10 seconds using as little paper as possible.

Materials Needed
• several single sheets of notebook paper with holes for a standard 3-ring binder
• *if possible,* self-adhesive hole reinforcements for both sides of the paper
• hole punch
• 2 pushpins
• scissors
• large paper clip (bent into an S shape)
• any object weighing about 750g (2 lbs.) that can be attached to the paper clip

Directions
1. Set up your simple bridge as shown in the diagram above.

2. Place hole reinforcements on both sides of the punched holes at the top left and right and on both sides of the punched hole at the bottom center.

3. Suspend the weight from the bottom center hole using the paper clip.

You should find that the bridge will hold your object without breaking. This is your prototype bridge.
**CHALLENGE**

Your task is to modify your prototype paper bridge by cutting away paper so that you can still support the same weight for 10 seconds with as little paper as possible.

Record what happens when you test your modified bridge. Use the data sheet below to record your findings.

**TEST 1**

Sketch your bridge design here:

- Did the design support the weight for 10 seconds?  **YES / NO**
- How will you improve your design for a subsequent test with a new piece of paper?

**TEST 2**

Sketch your bridge design here:

- Did the design support the weight for 10 seconds?  **YES / NO**
- How will you improve your design for a subsequent test with a new piece of paper?

**TEST 3**

Sketch your bridge design here:

- Did the design support the weight for 10 seconds?  **YES / NO**
- How will you improve your design for a subsequent test with a new piece of paper?
Approaches to Engineering Design

Approach 1
Many engineering projects that are undertaken in schools call for students to:

- build from scratch over long time periods; or
- test their design against the designs of competitors, for example, building a bridge made of toothpicks that will support a specified weight, creating a rubber-band-powered car that will travel the farthest, etc.

Approach 2
Sadler and his colleagues emphasize design projects that:

- provide students with manageable starting points (a prototype for their design),
- provide opportunities to test designs frequently to see if they meet a specific goal (tests against nature, not against other designs), and
- require record keeping to show the changes in the designs and the reasons for the changes.

Discuss with your colleagues your reaction to these two approaches to conducting engineering projects in schools. In particular, think about how well each approach may help all students to be able to:

- design a solution or product;
- implement a proposed design;
- evaluate completed designs or products;
- communicate the process of design; and
- see the connections between science, engineering, and technology.

Share with your colleagues any engineering design projects that you conduct with your students. Are there any changes that you may make as a result of today’s workshop?
For Next Time

Ongoing Activity

Reflective Journal

Look through the national and/or state frameworks, as well as your school system’s curriculum guide or text series for goals relating to design and construction (engineering and technology) projects.

As you reflect on your learning from Workshop 1, please consider the following:

- As a result of your participation in Workshop 1—Behind the Design, how has your understanding of national/state or school-system goals for design projects been impacted?
- What information from this workshop and from the Going Further discussions with colleagues will you use as you prepare future design projects for use in your classroom?
- What challenges do you face as you implement design projects and how might you go about addressing these?

Homework

Keep a list of your major activities (based in your house or in other places you go) on one weekend day and evening. Keep this list for your reference in the group discussion during Workshop 2.

Reminder: Sign up for a Web Buddy (see Workshop Components, p. 11).

Reading Assignment

To prepare for Workshop 2, please read the article by Marta Civil, “Bridging In-School Mathematics and Out-of-School Mathematics: A Reflection,” which can be found in the Appendix. Pay attention to her major topics: household visits, classroom implementation, parents as resources, and study groups.
Workshop 2
Mathematics: A Community Focus

DESCRIPTION
As teachers, we often make assumptions about the knowledge children are exposed to at home. Sometimes it seems that we focus on only reading and writing; Marta Civil contends that we need to look more carefully at the mathematical potential of the home. Strong parent connections to the school are essential to children’s learning. In this workshop, you will look at many aspects of children’s informal (home) knowledge; you will see and hear from Dr. Civil, the teachers she works with, and a long-standing parent mathematics group; and you will also follow a teacher on a family visit. Dr. Civil writes and speaks eloquently about “unlearning normalized ways of seeing and documenting minority families.” She believes it is essential that schools learn to be more flexible and knowledgeable about students’ homes.

DR. MARTA CIVIL
Associate professor of mathematics at The University of Arizona, Marta Civil specializes in mathematics education, and in particular, in mathematics teacher education for grades K-8 and in cultural and social aspects in the teaching and learning of mathematics. She has presented her work at national and international meetings and has several published papers and articles. Currently, she leads three funded projects—one on bridging in-school and out-of-school mathematics, another on parental involvement in mathematics, and a third on gender equity in science, technology, engineering, and mathematics. Most of her work has focused on working-class Latino communities.
Getting Ready

**Your Mathematical Weekend**

Last week's homework asked you to keep a list of your major day and evening activities for one weekend day. With the group, pool your weekend activities into one large list on chart paper or a chalkboard. Spend time identifying the mathematical underpinnings of as many of these activities as you can. For instance, did you do any sorting? Mapping? Spatial skills like packing or packaging? Sequencing? Finding patterns? What would you say were the mathematical (not only the arithmetical) activities you engaged in while you were just conducting your regular life?

**Connecting With Parents**

As a group, make a shared list of the kinds of parent involvement and parent activities that occur at your school. After you have completed the list, classify the activities according to location (home, school, or community); who initiates the contact (families or school); who attends (mostly families, mostly teachers); and who sets the agenda (home or school). Do you see any patterns in the data? What might explain what you see?
Workshop 2 Timeline

Watch the Workshop Video  
60 minutes

Going Further  
30 minutes

Reactions and Ideas
Talk with your group about the approaches that Dr. Civil and her colleagues are developing.

• What do you find striking about them?
• What questions does their work raise for you?
• What might you try or implement at your school site?

With your colleagues, think about and make a list of:

• factors that support teachers contacting families,
• factors that support families contacting teachers,
• factors that work against teachers contacting families, and
• factors that work against families contacting teachers.
Ongoing Activity

Reflective Journal
In your journal, think about your reaction to Dr. Civil’s ideas. What do you find intriguing or challenging? Does her approach point to any possible next steps in your teaching?

Homework

Observe your own teaching during a mathematics or science class. What patterns do you see in the dialogue? (For example: Are you asking a lot of questions? Are you allowing much “wait time” after a question? [Three seconds is supposed to make a real difference in the number and quality of students’ responses.] What kind of questions are you asking? Do students ever ask each other questions or challenge each others’ ideas?)

Keep track of your data and some of your analysis in your journal.

Think of a discussion your class has had in mathematics or science. Jot down enough so that you will be able to remember it for group discussion during Workshop 3. What was so interesting about it? What was satisfying? What role did you play? What other aspects of the discussion were important to you?

Reminder: Sign up for a Web Buddy (see Workshop Components, p. 11).

Reading Assignment

To prepare for Workshop 3, please read the article by Carne Barnett and Alma Ramirez, “Fostering Critical Analysis and Reflection Through Mathematics Case Discussions,” which can be found in the Appendix. As you read it, think about other professional development experiences you’ve had. How do they compare to what you are reading here?
Workshop 3
Learning to Share Perspectives

DESCRIPTION
Often teachers complain that they do not have ample opportunity to talk with colleagues about their students' mathematical reasoning. In this workshop you will learn about professional development focused on the discussion of cases in mathematics teaching. Carne Barnett describes this case approach. A long-term teacher group is shown at work. The development of cases for children in elementary and middle school mathematics classes is highlighted as an evolving approach to furthering the development of their mathematical thinking.

DR. CARNE BARNETT
Carne Barnett is a senior research associate at WestEd in Oakland, California, where she directs the Mathematics Case Methods Project. Teachers in this professional development project discuss cases about mathematics teaching dilemmas. Dr. Barnett’s own teaching experiences led to her interest in this pioneering work, which is patterned after methods used in other professions such as business and health. She has written numerous books for teachers and students and has been published in research journals. She was formerly a teacher educator at the University of California, Berkeley, and has conducted professional development across the United States and in Malaysia, Australia, and Saipan.
Teaching Patterns

Last week your homework was to observe your own teaching, focusing especially on elements of discourse. Using some of the self-observation information from your reflective journal, share some of the patterns you saw in your own teaching of mathematics or science. With the group, make a master list of the kinds of patterns you all recorded. Are there common themes across the group?

Take what you’ve learned one step further and begin to incorporate some of the principles into your own teaching. With your Web Buddy, share some of the ideas you have for incorporating a case approach to your own mathematics or science classes. Support each other’s beginning ideas and try to take some steps. Report to your Web Buddy about your successes!

Take One-Third

Materials Needed

- 16 beans or other discrete objects (thumbtacks, erasers, small blocks)

Preview the Problem

Please work on the following problem by yourself so that you can examine your own ideas. As you work, think about what might be hard or confusing to a child (or to you).

On your own, draw a picture in which you take 1/3 of 1 1/3. Hint: Start with a picture of 1 1/3.

Read the Case

Silently, read the case “Take One-Third,”* which follows. You will refer to this case in your site discussion during the video.

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State Issues in Question Format
With your group, discuss the issues that the videotape raises. Follow the case discussion procedure.

In pairs, first list three or four issues in question format. Some stems you might find useful are:

- Why might a student…
- What might happen if…
- What does ______ mean?
- What if the problem/manipulative were…

Share those issues with the rest of the group. (Usually it works best if you go around the group, with each pair contributing one issue at a time.) One member of the group might record comments on a large piece of chart paper or on the chalkboard.

Pick one of the questions and talk about it as a group.
For Next Time

Ongoing Activity

Reflective Journal
In your journal, answer the following:

• How do you attempt to find out about children’s ideas when you teach a science topic?
• How do you structure lessons to help children examine their ideas?
• What frustrations do you feel around helping students develop concepts?

Homework

Children and adults have formed a variety of interpretations of their world throughout their lifetime. Many of these interpretations do not fit with the way science explains the world.

For instance, you may have heard children say some of the following:

• Solids are things that are hard.
• Because air is invisible, it doesn’t take up any space.
• We don’t need light to see because our eyes will adapt.
• Plants get their food from the soil.
• The phases of the moon are caused by clouds.
• The summer is hot because the Earth is closer to the Sun.

In your journal, answer the following:

• How do you attempt to find out about children’s ideas when you teach a science topic?
• How do you structure lessons to help children examine their ideas?
• What frustrations do you feel around helping students to develop concepts?

Reminder: Sign up for a Web Buddy (see Workshop Components, p. 11).

Reading Assignment

To prepare for Workshop 4, please read the article by Peter Hewson, “Conceptual Change in Science Teaching and Teacher Education,” which can be found in the Appendix.
**Take One-Third**

As my seventh and eighth graders entered our classroom and found their seats, their attention turned to the “starter problem” written on the overhead. I asked them to work on it silently in preparation for the day’s lesson on multiplying fractions.

*On your own, draw a picture where you take $\frac{1}{3}$ of $1 \frac{1}{3}$. Hint: Start with a picture of $1 \frac{1}{3}$*

I finished administrative tasks as the students worked, then walked around to look at their pictures. I decided to ask Linda and Bob to show their solutions on the board, so that I could illustrate the use of both continuous and discrete fractions. We turned first to Linda’s picture.

“**How did you start the problem, Linda?**”
“I just drew 1 and $\frac{1}{3}$,” she said.
“So this circle represents a whole, and this piece is $\frac{1}{3}$ of another equal-sized whole?”
“Yes.”
Several students commented that they had drawn very similar pictures. I asked Linda to explain how she solved the problem.
“I just took away $\frac{1}{3}$ from 1 and $\frac{1}{3}$,” she answered, as she crossed out the $\frac{1}{3}$.
“Listen to what you just said,” I prompted.
“I just took away $\frac{1}{3}$ from 1 and $\frac{1}{3}$,” Linda insisted.
“What operation did you say out loud?” I asked.
“Take away — subtraction.”
When I directed her attention back to the problem on the overhead, she looked confused, saying: “Take $\frac{1}{3}$ of $1 \frac{1}{3}$. I don’t get it. This is weird.”
Still hoping the class would be able to discover the proper procedure on its own, I switched to Bob, expecting that his solution would be both correct and easier for the class to understand.
He explained how he started. “I thought of 9 spots being in the whole and then 3 more would be $\frac{1}{3}$.”

“So how did you find $\frac{1}{3}$ of $1\frac{1}{3}$?”

“I just took $\frac{1}{3}$,” he replied indicating three of the spots.

“You should take 4,” Jim and a few other students cried out. I asked them to think about what it means to take $\frac{1}{3}$ giving a hint by pointing to the denominator.

“Divide them into 3 equal groups,” Amanda volunteered, “and you get 1 of those groups or $\frac{1}{3}$.”

Then I attempted a real life example that would relate Bob’s problem to the previous day’s lesson. I asked them to imagine that Bob’s items were popsicles and to think about $\frac{1}{3}$ of all of them. Bob could get one part, his brother another equal part, and his mom another third. His dad is on a diet. How many popsicles would it be fair for Bob to eat? Jane and several students said 4, a few said 3. I called on Jane to explain.

“$\frac{1}{3}$ of 12 is 4. You just divide,” she replied.

“So we weren’t supposed to take away $\frac{1}{3}$. These are division problems,” Max realized. “Why didn’t you tell us?” The whole class was a little unhappy with my “deception.”

All this took place in a general math class in a medium-sized suburban middle school with 850 students. There were twenty seventh graders and six eighth graders in the class. I had chosen fractions as one of my teacher-evaluation curricular areas for the year.

I had begun the unit by giving a pretest on basic fraction concepts and operations, including some word problems. Because the scores were on average very low, I decided to spend a couple of months working with these ideas so my students would show substantial growth on the post-test.

We spent the first few weeks developing meaning for fractions, placing a strong emphasis on being able to draw a picture of a fraction amount. Most pictures showed subdivisions in rectangles, with number lines being used occasionally. I offered examples of work with discrete fractions, such as $\frac{12}{24}$ meaning 12 of the 24 original pieces of candy in a box, which in turn means the box is half full. By the time we reached the current lesson, the students also had some experience drawing representations of subtraction problems such as:

$$\frac{1}{2} - \frac{3}{8}$$

On the day before this lesson the students had worked on pictures that introduced the concept of fraction multiplication. They had sketched problems such as $\frac{1}{3}$ of 27 pieces of gum and had figured $\frac{1}{4}$ of 16 candies. The word multiplication had not been formally used at this point.

So here we were trying to begin a lesson on multiplying fractions, and now Linda’s work had revealed that she thought we were talking about subtraction. Then, from Bob’s example the class had impulsively concluded that “you just divide.” I wondered if it had been a mistake to follow my usual custom of having students experiment with a new concept on their own before the formal lesson. Was it practical—or possible—to capitalize on these misunderstandings and proceed with the lesson? Or should I have started over and approached the lesson by giving a little more guidance?

I now see that similarities in the language of multiplying and subtracting fractions call for a careful choice of words. But beyond that, my own understanding of fractions has been shaken Max’s statement. It seems that you do divide when multiplying fractions. But how am I going to make sense of that to my students?
Workshop 4
Conceptual Change

DESCRIPTION
In this workshop we will explore the role played by prior knowledge when learning new science ideas. Only when a new idea is understood, accepted, and found to be useful does it begin to be exchanged for a previously held scientific belief. The workshop will also examine how teachers’ ideas about teaching and learning may be altered as they engage students in strategies designed to promote conceptual change.

DR. PETER HEWSON
Professor of science education at the University of Wisconsin-Madison, Peter Hewson studies how students learn science, how teachers teach science, and how people become teachers of science. In doing so, he uses ideas about conceptual change as a common theme in understanding the complexity of practice in classrooms with diverse human beings. He is a co-author of Designing Professional Development for Teachers of Science and Mathematics, published in 1998, and is currently working on teacher professional development in a joint collaboration between the U.S. and South Africa.
Children's Science Ideas

Share with your colleagues your thinking about working with children’s alternative science ideas. As you discuss these ideas, write down in your journal anything that you hear from your colleagues that you might find of use in your classroom.

- Describe some ideas that your students hold that may often hinder their learning as you teach a particular topic.
- Discuss the methods that you use (or could use) to find out what students’ existing beliefs are as you teach a new concept.
- How do you create an atmosphere in which students are willing to share their thinking?
Conceptual Exchange

In this workshop, we have seen that if students are to accept a new scientific concept, it must be intelligible (they must know what it means), plausible (it is believable), and fruitful (it is useful to them).

In your group, discuss the following questions:

• Is this concept of teaching science intelligible to you? (Can you describe and explain what is necessary?)

• What in today’s workshop has made this idea of science teaching plausible or not plausible for you? (i.e., do you believe that teaching for conceptual change really assists students in learning science concepts?)

• In the classroom footage, what atmosphere was created to encourage students to freely express their thinking?
For Next Time

Ongoing Activity

Reflective Journal

In this workshop, Peter Hewson discussed the need to “lower the status” of alternative science ideas held by students, while “raising the status” of the science idea that you want students to attain.

In your journal explain how you might go about lowering the status of an “incorrect” science idea. You might want to make specific reference to helping children in your class to change their ideas about a concept you have taught recently.

Homework

A part of our work as teachers is to assist students in the development of their thinking skills. But what do we mean by thinking skills?

Make a list of all the terms that you associate with the term “thinking skill”—e.g., analysis, creative thinking, etc.

How would you define each of these terms, or what would you expect your students to be able to do if they possessed the thinking skill?

Reminder: Sign up for a Web Buddy (see Workshop Components, p. 11).

Reading Assignment

To prepare for Workshop 5, please read the article, “Critical and Creative Thinking in Science” written by Robert Swartz and taken from his book Infusing the Teaching of Critical and Creative Thinking into Secondary Science. The article can be found in the Appendix.

For your information

The Genetics Construction Kit (GCK) is published as part of The BioQUEST Library. For further information about The BioQUEST Library, please contact the BioQUEST Curriculum Consortium at:

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Workshop 5
Infusing Critical and Creative Thinking

DESCRIPTION
Teachers can help students become good thinkers. Good thinkers are able to raise key questions and gather and evaluate pertinent information; thus making informed decisions. But how do we teach students to not just think, but think skillfully? Many critical and creative thinking programs advocate the explicit teaching of thinking skills. In this workshop, we will see and hear how thinking skills can be infused into science content instruction, and contrast this method with direct instruction in thinking skills in non-curricular contexts. We will visit classrooms where teachers have restructured their lesson content to infuse thinking skills and, in the process, have added richness and depth to their students’ learning.

DR. ROBERT J. SWARTZ
Robert Swartz received his Ph.D. in philosophy from Harvard University. He is a faculty member at the University of Massachusetts at Boston and the director of the National Center for Teaching Thinking. Through the Center, he provides staff development to educators across the country on infusing critical and creative thinking into content instruction. He has authored numerous articles and books on critical thinking and has acted as a thinking-skills testing consultant for the National Assessment of Educational Progress.
### Workshop 5 Timeline

#### Getting Ready  

**30 minutes**

**Thinking Skills**

Prior to this workshop, you made a list of all the terms that you connect with “thinking skills.”

- Compare your list with the lists made by your colleagues.
- Develop group definitions for the terms included in your lists.

Describe how instruction in thinking skills occurs in your teaching. What do you hope you will learn more about during this workshop to assist you in the teaching of thinking?
Workshop 5 Timeline

Watch the Workshop Video

Going Further

Components of an Infusion Lesson

On the following page, you will see a schematic* illustrating the components of an infusion lesson.

Take five minutes to individually read through the schematic. With your colleagues, discuss each component in turn:

Introduction to Content and Process

• What do you understand by this component?
• What examples did you see, read, or hear about in this workshop that illustrate this component?

Thinking Actively

• What is happening in this component?
• What is the teacher’s role?

Thinking About Thinking

Applying the Thinking

• What value do you think these two components add to the teaching of thinking skills?

For Next Time

Ongoing Activity

Reflective Journal

Return to the thinking skills terms that you defined with your colleagues.

In your reflective journal, describe how your understanding of and the teaching of thinking skills has developed as a result of your participation in Workshop 5.

What questions remain in your mind about the teaching of thinking skills? (You might add these questions to Channel-Talk for comment by other teachers.)

What kind of thinking have you just engaged in, in order to respond to the points above?

Homework

- In your reflective journal, write about what you remember of your own algebra and/or calculus experience. What were the highlights? What puzzled you or made you uncomfortable?
- Interview at least two colleagues about what they remember of algebra and why they had to learn it in high school. Jot these responses down. Bring them to the next session.

Reminder: Sign up for a Web Buddy (see Workshop Components, p. 11).

Reading Assignment

To prepare for Workshop 6, please read the article by James Kaput, “Transforming Algebra from an Engine of Inequity to an Engine of Mathematical Power by ‘Algebrafying’ the K-12 Curriculum,” which can be found in the Appendix.
COMPONENTS OF INFUSION LESSONS

INTRODUCTION TO CONTENT AND PROCESS

Teacher's comments to introduce the content objectives
The lesson introduction should activate students' prior knowledge of the content and establish its relevance and importance.

Teacher's comments to introduce the thinking process and its significance
The lesson introduction should activate students' prior experience with the thinking skill/process, preview the thinking skill/process, and demonstrate the value and usefulness of performing the thinking skillfully. The introduction serves as an anticipatory set for the thinking process and should confirm the benefits of its skillful use.

THINKING ACTIVELY

Active thinking prompted by teacher questioning and graphic maps
The main activity in the lesson interweaves the explicit thinking skill/process with the content. This is what makes the content lesson an infused lesson. Teachers guide students through the thinking activity by using questions phrased in the language of the thinking skill/process and by using graphic organizers.

THINKING ABOUT THINKING

Distancing activities that help students think about the thinking process
Students are asked direct questions about their thinking that prompt them to reflect about what kind of thinking they did, how they did it, and how effective it was.

APPLYING THE THINKING

Transfer activities that involve student-prompted use of the skill in other examples
There are two broad categories of transfer activities: (1) near or far activities that immediately follow the substance of the lesson and (2) reinforcement of the thinking later in the school year. Both types of transfer involve less teacher prompting of the thinking process than in the Thinking Actively component of the lesson.

Immediate transfer
Near transfer
Application of the thinking process within the same class session, or soon thereafter, to content similar to that of the initial activity in the lesson. Decreased teacher prompting of the thinking is involved.

Far transfer
Application of the thinking process within the same class session, or shortly thereafter, to content different to that of the initial activity in the lesson. Decreased teacher prompting of the thinking is involved.

Reinforcement later
Application of the thinking process later in the school year to a variety of both near and far transfer
DESCRIPTION
Professor James Kaput of the University of Massachusetts, Dartmouth, studies children’s understanding of algebra and calculus. Historically, these topics have presented students with significant problems, and we tend to see it as a given that children will struggle with them. Professor Kaput finds many ways of embedding algebra and calculus concepts into the curriculum much earlier in the school experience so that children are no longer asked to think about them as separate from their prior mathematics work.

PROFESSOR JAMES J. KAPUT
Chancellor professor in the Department of Mathematics at the University of Massachusetts, Dartmouth, James Kaput specializes in elementary students’ development of algebraic reasoning and the development of affordable technologies for mathematics education. Dr. Kaput has recently turned his attention to the massive implementation of technology-based innovations to democratize access to powerful mathematics, especially among disadvantaged populations. He is on the editorial board of six mathematics education journals and is a founding co-editor of a new series of volumes sponsored by the Conference Board of the Mathematical Sciences on Research in Collegiate Mathematics Education.
Workshop 6 Timeline

Getting Ready

30 minutes

Sharing Ideas

In group discussions:

• Develop a group definition of the term “algebra.”
• Collect the group’s ideas about the purpose of calculus.
• Share your personal recollections of learning algebra or those of the people you interviewed.
• Discuss the common features of your responses.

The Painted Cube Problem

Start individually, then join with a colleague to discuss the following:

• Imagine that you have a cube that you dip into paint. How many square surfaces are covered with paint?
• Imagine linking another cube to this one, with two flat ends butted together. Imagine dipping this train of two cubes into paint. How many unit square surfaces are painted this time?
• Make a train of three cubes (end to end). How many square surfaces are painted now?
• Extend and explore this problem to find ways of predicting how many surfaces are painted for:
  • 10 cubes,
  • 25 cubes, and
  • 100 cubes.

We will return to this painted cube problem in the Going Further section.
Workshop 6 Timeline

Watch the Workshop Video 60 minutes

Going Further 30 minutes

Return to the Painted Cube Problem

Look at the way in which you represented the data for 10, 25, and 100 cubes.

• Share strategies and ways of thinking about this problem.
• What are the simplest ways of representing the problem?
• Have each member of the group describe what they found surprising or intriguing about the painted cube problem.
• What aspects of this problem are truly algebraic?

This problem is a classic. You may want to see what your students make of it. Even young students can find and represent the patterns of growth in this cube train.

Reflecting on Algebra and Calculus

Spend some time with your group revisiting your initial ideas about calculus and algebra.
For Next Time

Ongoing Activity

Reflective Journal
Think about how Professor Kaput defines algebra. Describe ways you may be doing algebraic work in your classroom, but have not formally identified it as such.

Homework

How do you know if your students really understand the mathematics (or science) concepts you teach? List the ways you assess their understanding and compare the “yield” in knowledge you gain from each assessment strategy.

Reminder: Sign up for a Web Buddy (see Workshop Components, p. 11).

Reading Assignment

To prepare for Workshop 7, please read the article by Herbert Ginsburg, “Young Children Doing Mathematics,” which can be found in the Appendix.

For Your Information

To obtain a copy of the SimCalc computer software, go to http://www.SimCalc.umassd.edu or contact:

Kevin Zeppenfeld, SimCalc
Project Manager, 128 Chase
University of Massachusetts-Dartmouth
285 Old Westport Road
North Dartmouth, MA 02747-2300

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Workshop 7
Children’s Ways of Knowing

DESCRIPTION
Children know a good deal of informal mathematics before they enter school. Clinical interviews help teachers understand what children know. In this session, you will see young children’s natural mathematical inclinations and watch as they construct their ideas. You will observe Professor Ginsburg helping teachers of young children rethink the mathematics curriculum based on children’s natural mathematics work.

PROFESSOR HERBERT GINSBURG
Professor Herbert Ginsburg holds the Jacob H. Schiff Chair at Teachers College, Columbia University, where he is professor of psychology and education. For the past 30 years, he has conducted research on cognitive development—particularly the development of children’s mathematical thinking—both within the U.S. and in various cultures around the world. He has used the knowledge gained from research to develop several kinds of educational applications and has created video workshops to enhance teachers’ understanding of their children’s learning of mathematics. He has also contributed to the Silver Burdett & Ginn mathematics textbook series, developed tests of mathematical thinking, and explored how the “clinical interview” method for assessing children’s mathematical knowledge can be used by teachers in their classrooms. Currently, he is engaged in research on young children’s mathematical competence and is developing a new mathematics curriculum for 4- and 5-year-old children.
Getting Ready

Understanding a Question
Think of a time when a child asked you a question or said something you just couldn’t follow. Describe it to your colleagues. As a group, select one instance and discuss it. Try to find the logic the child was expressing and identify the confusion you had.

Early Mathematics
Discuss with your colleagues:

• Based on your own experience, what mathematics concepts do 4- and 5-year-old children know?
• What mathematics concepts are 4- and 5-year-old children developing naturally?
Workshop 7 Timeline

Watch the Workshop Video 60 minutes

Going Further 30 minutes

Children’s Thinking
Were there any surprising aspects of the children’s work? Think of some strategies teachers could use to connect these informal mathematical ideas with “school math.”

Interviewing
Talk with your colleagues about the opportunities and challenges that clinical interviewing presents to teachers.
For Next Time

Ongoing Activity

Reflective Journal
In your journal, write about a time you felt mathematically misunderstood. What sort of help from a teacher might have been most beneficial to you?

Homework

Before the next workshop, ask your students to explain (in writing and drawings) what they understand about one idea that you have recently taught in science.

• Take a close look at what your children have written and drawn.
• List any ideas that you see in the children’s work that do not seem to fit with the concept you taught.
• What questions could you ask to gain more information about student thinking?
• List any ideas expressed in the children’s work that might be turned into simple investigations.
• Bring a few representative samples of children’s work (erase names) to Workshop 8 for the Going Further discussion.

Reminder: Sign up for a Web Buddy (see Workshop Components, p. 11).

Reading Assignment

To prepare for Workshop 8, please read the articles by Wynne Harlen, “Handling Children’s Questions”—taken from her book The Teaching of Science in Primary School—and “Assessment in the Inquiry Classroom,” which can be found in the Appendix.
Workshop 8

Learning to Listen

DESCRIPTION

Formative assessment is a term that has gained prominence as teachers recognize the value of uncovering students’ thinking during the course of instruction. This information is then used to guide the development of lessons as well as provide feedback to students to assist them in their learning. In this workshop, we see teachers encouraging students to ask questions, thus affording them the opportunity to test their ideas and restructure their own thinking.

DR. WYNNE HARLEN

Wynne Harlen worked as a professor of education at universities in Reading, London, and Liverpool before being appointed as the director of the Scottish Council for Research in Education. She has spent her working life in research, development, and evaluation of children’s learning in science. Her particular concerns are to help teachers help children learn with understanding and, through the use of scientific process skills, to develop concepts, attitudes, and values that promote scientific literacy, lifelong learning, and respect for the environment. Her 16 books include Taking the Plunge, The Teaching of Science in Primary Schools, and the recently published third edition of Teaching, Learning and Assessing Science.
Getting Ready

Observation Skills

Five Minutes
Working individually, choose an object in the room but do not tell anyone what you have chosen. Then, write a paragraph which describes the object (but does not name it). Your paragraph should illustrate your observation skill.

Five Minutes
Depending on the size of the group, either read your description and let the whole group identify the object, or swap your description with one person and see if they can identify the object.

Twenty Minutes
Now imagine that you had asked your students to complete this observation exercise. How would you assess the quality of their descriptions?

Discuss what you would look for in your students’ paragraphs that would illustrate to you that their observation skills are developing appropriately. (You might develop an observation skill assessment scheme in order to decide which students need more assistance.)

Discuss how you would assist students in future lessons if their paragraphs showed that they needed support in developing the skill of observation.
Workshop 8 Timeline

Watch the Workshop Video  
60 minutes

Going Further  
30 minutes

Student Work
Preparation
You were asked to bring examples of children’s work to discuss. If you were unable to bring any, use the example responses given below.

Example Responses
Listed are the types of responses that could be expected from elementary children when asked, “Why can you hear a tuning fork after it has been struck and is then held on a table?”

A. Tuning forks make sound waves that aren’t loud.
B. The tuning fork was hit and it vibrated. The table made it louder and the sound waves went through the air to my ear.
C. The tuning fork vibrates and this vibrates the table. The air vibrates and that vibrates my eardrum so that I hear its noise.
D. The fork makes a noise and I hear it hum on the table if I listen hard.

Discussion
Using either your own examples or the ones provided, show your colleagues examples of how several children in your class thought somewhat differently about a science idea they had learned.

When you have each described your examples:

• Choose the work of one child whose idea needs further refinement. Discuss how you might structure a lesson (for the whole class or for a small group) which might help to clarify the concept for children.
• Discuss how the responses differ.
  • Were terms used by the children that did not completely convey their understanding?
  • For each set of children’s work you have discussed, choose the work of one child whose idea needs further refining. Develop a series of questions that you might ask him/her in order to gain more information about the child’s thinking.
Final Assignments

Ongoing Activity

Reflective Journal

In this workshop, you have read about and seen the use of assessment during the course of instruction. Looking at students’ learning in progress and not just at the end of a unit of instruction is the means by which we help children better understand concepts and master skills.

• What do you currently do to keep track of each student’s learning?

• What personal data-management issues do you envision or face as you document students’ learning during instruction?

• What did you see or hear in today’s workshop (either from the video or from discussions with your colleagues) that you think you might like to use in your own classroom?

• How important to you, personally, is it to find out about children’s thinking during the course of instruction?


Other Resources

Hewson, Peter. Genetics Construction Kit computer program. Go to http://bioquest.org or call (608) 363-2743.

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Appendix

Index of Readings

The Reading Assignments, below, correspond with the workshops of the same number.


About Project DESIGNS

Project DESIGNS Goals that Cross All Modules

Each of the six DESIGNS modules contains three or more challenges. Embedded within each challenge of every module are three important goals. They are as follows:

1. **Support learning through clear student goals.** Each student goal is presented as a clearly defined challenge in physical science. These challenges are invitations to students to improve the performance of a simply designed device commonly found in their world.

2. **Empower students as problem-solvers.** Students are encouraged to use their prior knowledge to develop strategies to make progress in each DESIGNS challenge. Students discover and utilize physical science concepts as they achieve the goal characterized by the challenge.

3. **Encourage students to be critical creators of knowledge.** Students propose, test, and eventually defend their ideas. Teachers probe student strategies and interpretations, and encourage students to assess their own and other's evidence.

Students quickly recognize the goal that is posed as a challenge. For example, if the challenge is to improve a working model of a windmill, students easily visualize what is expected and what constitutes a successful outcome. The student who encounters the poorly designed windmill interacts with the basic model, decides what might be changed, makes those changes, and evaluates the results. DESIGNS makes two important assumptions about students who accept the challenge: 1) they understand the goal, and 2) they accept the goal as their own. Students who accept ownership of the goal are more likely to be motivated to complete the work they begin. Students also appreciate the link between each DESIGNS challenge and its real world application. Student interaction with science is often through the technology that results from scientists' work. Each challenge offers students an interesting task centered on the theme of improving an existing design (e.g., a windmill, a battery, or an electromagnet).

DESIGNS challenges were crafted so that students could easily recognize the goal, quickly obtain feedback from their work, and effectively act on that feedback. This strategy is intended to invite students to act, and to empower and support their learning once they accept the invitation. Students who accept the challenge soon find that the problem becomes very compelling. They are motivated for several reasons. The iterative nature of the activity provides timely feedback. The feedback provided by nature is always available, always impartial, and typically unambiguous. Students can quickly determine if their ideas and actions are bringing them closer to the goal they recognized in the challenge. The interaction between the DESIGNS challenge, the supportive teacher, and the problem-solving student is critical in helping students to be self-directed, critical creators of knowledge.

DESIGNS challenges/goals are also intended to encourage teachers to continually assess whether the classroom setting supports student work in meeting the module goals. From this perspective, teachers focus on encouraging students to follow their own convictions. As a result, students are less dependent on the instructor for the "right answers." Instead, they seek to improve the strategies they use in meeting the design challenge. Often great progress is made when students discover that their beliefs are not supported in nature. Students who learn to question nature directly learn to increasingly value their experiments and become more interested in their results. Students who are motivated to accept the challenge need less assistance from the teacher to proceed. Students uncomfortable with this freedom may still seek the teacher's help. However, teachers who let the challenges guide the students help build students' confidence in their problem-solving ability. Teachers ultimately act to support student understanding of how science proceeds instead of what science has produced.

**DESIGNS Versus National Standards**

DESIGNS' goals agree philosophically with the following goals for school science as articulated in the National Science Education Standards (p. 13):

- Experience the richness and excitement of knowing about and understanding the natural world.
- Use appropriate scientific processes and principles in making personal decisions.
- Engage intelligently in public discourse and debate about matters of scientific and technological concern.
However, in an attempt to go beyond philosophical agreement with these goals, DESIGNS strives to create guiding principles that help direct the work of students and teachers. To this end, DESIGNS’ goals support the grades 5-8 Content Standards in the National Science Education Standards for Science as Inquiry which include (p. 143):

- Abilities to do scientific inquiry.
- Understanding about scientific inquiry.

Furthermore, DESIGNS’ goals directly support the grades 5-8 Science and Technology requirements in the National Science Education Standards. In particular, DESIGNS seeks to create opportunities for children so that, “as a result of activities in grades 5-8, all students should develop abilities of technological design” (p. 161). The underlying objective is that students will be able to perform the following (pp. 165-166):

- Identify appropriate problems for technological design.
- Design a solution or product.
- Implement a proposed design.
- Evaluate completed technological designs or products.
- Communicate the process of technological design.

All DESIGNS goals provide a framework to support scientific inquiry and technological design. This framework is the foundation on which students distinguish the difference between science and technology. Students work towards recognizing that the goal of science is to create knowledge, while the goal of technology is to apply that knowledge into developing the tools people use to solve problems. To support experimenting as well as the building of tools DESIGNS uses materials that are inexpensive, readily available and easily recognized by students as common items that constitute a part of their everyday world.

Skills that Cross all Modules

Science is a unique tool for understanding nature. It assumes that systems (such as the devices in a module) can be understood by first breaking them down into parts that can be later modified. Students learn by making changes to the variables they identify within a design (e.g., increasing the number of wire wrappings in an electromagnet). Students are encouraged to experiment, generate ideas, formulate conclusions, and support their ideas and conclusions with explanations. At the end of the project the students should be able to perform the design process and fabricate their best designs. As a result, they formulate and articulate theories about how each design works. Whether their theories are naive or sophisticated, students test their beliefs through each of their design modifications.

An important outcome of the module goals is that students develop both manipulative and cognitive skills in science. Three skills in particular are realized through student work:

1. **Articulating and testing prior notions about how a design works.** In many ways this skill represents the traditional view of what scientists do: asking questions, forming hypotheses, testing those hypotheses, etc. Students can easily identify the parts of the devices with which they are working. These “parts” represent the design variables that students can control as a scientist or engineer might. Students want to know what will happen to their designs when they choose to modify, add, or remove variables. Their questions become the guiding principles behind how they test their ideas.

2. **Judging the impact or magnitude of a change.** When a student wonders how a change might impact the original design, the student is posing the question directly to nature. Once the change has been implemented, nature provides the answer. Students judge the impact of their own ideas. They see that not all changes result in the same effect or even have any effect. Because the teacher is outside the question-answer cycle, students concentrate on looking to nature to find answers to their questions.

3. **Making convincing arguments that a change has resulted in a meaningful improvement to the design.** Students are expected to evaluate the impact of changes as well as judge the magnitude of change. They are encouraged to employ tools (such as graphs, tables, and charts) to support claims that some changes had a greater impact than others, or that a change had no impact at all.
To the extent that these skills are practiced in the module, DESIGNS supports the broadest standard in the National Science Education Standards. “As a result of activities in grades K-12 all students should develop understanding and abilities aligned with the following concepts and processes” (p. 117-118):

- **Evidence, models, and explanation**: Evidence consists of observations and data on which to base scientific explanations. Using evidence to understand interactions allows individuals to predict changes in natural and designed systems.
- **Constancy, change, and measurement**: Energy can be transferred and matter can be changed. . . . Changes can be quantified. . . . Different systems of measurement are used for different purposes.
BRIDGING IN-SCHOOL MATHEMATICS AND
OUT-OF-SCHOOL MATHEMATICS: A REFLECTION

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In this paper I present mostly a personal reflection on some aspects of our work in the research project BRIDGE1. The goal of this project is the development of mathematics teaching innovations in which students and teachers engage in mathematically rich situations through the creation of learning modules that capitalize on students' (and their families') knowledge and experiences in their everyday life. To accomplish this goal and the associated research questions, we rely on a model that has four key inter-related components: 1) Household Ethnographic Analysis; 2) Teacher-Researcher Study Groups; 3) Classroom Implementation; and 4) Parents as Learning Resources. I will briefly describe these four components, but my focus will be on the Study Groups as the setting where we work on bridging in-school and out-of-school knowledge.

Background

Our work takes place mostly in classrooms where the majority of students is of Mexican origin and economically disadvantaged. We reject a deficit theory model for the mathematics education of minority students. Such a model presupposes that the households of minority, working-class children are at the root of “the problem.” That is, this model assumes that students lack adequate experiences and background for formal schooling. In this model, students are often cast in a passive role and perceived as “lacking something.” Instead, our research is grounded on the sociocultural approach to education that was developed in a prior project— Funds of Knowledge for Teaching (González, 1995; Moll, 1992). Findings from that project show a wealth of resources and information in these children's households that often is untapped in school (examples of funds of knowledge include ranching and farming; budgets; construction; folk medicine). Furthermore, that project also gathered evidence that at home and in their community, these children are often active participants in the functioning of the household (e.g., language interpreters for parents and other relatives; assist in the child care of younger siblings; help out in the economical development of the household). A key premise in our work is to capitalize on the students' (and their families') experiences and knowledge as learning resources in school. How does this premise carry over to mathematics education? What kinds of mathematics can we extract from their experiences and practices? And how can we relate them in a truthful manner to the content and the ways of school mathematics? How can students' mathematical experiences outside school be brought to the foreground in ways that help them advance in their learning of school mathematics? (Civil, 1995a) These are key questions for us in our study group sessions. Exploring the issue of pedagogical transformation of household, out-of-school mathematical knowledge into modules, themes, ideas that connect with in-school mathematics encompasses much of what takes places in the regular study group meetings.

Who are we?

Currently, there are 5 University based researchers (anthropology, bilingual education, mathematics education); 3 middle school teachers (one of whom is on leave at the University just for this year); 5 elementary teachers (third, fourth, and fifth grade). There are two other teachers (one elementary, one middle school) who have participated in the past and are still interested in being in the project, but have not been involved in the last few months. In this paper, I will refer to the 8 teachers who are currently actively engaged in the project.

The middle school and two of the elementary schools serve a working class student population (90% to
95% Latino). The third elementary school serves a middle class population with a 35% to 40% Latino. One of the schools follows a very specific mathematics curriculum, based on a reform oriented textbook series. The other three schools have a less structured curriculum.

One aspect worth documenting is the commitment that such a research project entails. I am not only referring to time commitment, but to the fact that in this project we (where we is all of us) are working together towards the general research goal. We do not have a clear, linear process that we are following to get “there.” I have been involved in professional development projects in mathematics, and so have many of the teachers currently participating in BRIDGE. In BRIDGE, there is a strong research component: the teachers are researchers (when they go into their students’ homes, when they present and analyze findings in the study groups, when they read related articles and work on making connections to their classrooms, when they develop learning themes and try them out in the classroom). This in itself is often different from what teachers have experienced (e.g., inservice type experiences in which teachers are at the receiving end of ideas on how to teach mathematics). We are working together towards a common goal (that is open to different individual interpretations) which means that at times, things are fuzzy. We do not have an exemplary curriculum that we all explore together, or a series of activities on a specific topic in mathematics that we look at. Sometimes we explore mathematics as both learners and teachers, but many times, we are trying to make sense of how to build on students’ diverse experiences in a way that does help them advance in their mathematical learning in school. And this issue takes different forms for each of us in this project. It is in this sense that I view BRIDGE as different from most professional development experiences that the teachers and myself have taken part in.

In BRIDGE, we are a small group, and thus we try to accommodate each individual’s needs and interests. We (as in “staff”) do not come in with a model to follow. We (all of us) are trying to develop that model. We bring in different experiences, needs, and interests. This diversity certainly influences the structure of the study group discussions. The mathematical backgrounds and experiences of the participating teachers are quite varied. Most of them are experienced teachers. Six of them are bilingual and teach in bilingual classrooms. As for the reasons given for wanting to participate in project BRIDGE, they are equally varied. For example, one of the teachers has had prior experience with study groups and being a teacher-researcher. She enjoys the University-School collaboration, and knows what this collaboration must look like for her to be willing and comfortable to take part in it. The reason why she joined this project is because she, herself, was intrigued by the question: “Can rigorous mathematics be developed from everyday mathematics?” She formulated this question, which ties directly to my research interest in this project. She is in the project to research this question, which ties directly to my research interest in this project. She is in the project to research this question by having access to the mathematical resources in the group. Another teacher not only has a very solid mathematics background but also had previously taken a University course that focused on ethnographic training for the household visits, and was therefore familiar with the spirit of the current project. He has developed a very successful curriculum project for his seventh and eighth graders around the theme of “Build your dream home” (Fonseca, 1997) and has in a sense provided an “existence proof” to our research problem, a “yes, it can be done” type of experience. He is particularly interested in curriculum development that is grounded in students’ experiences and in its assessment. Some of the teachers are particularly interested in the ethnographic component and in reaching out to their students’ parents and the community in which they teach. Some are
interested in the mathematical focus and view this project as a way to explore new ways to teach mathematics.

Another key factor that directly affects the dynamics of the study groups are the changes in participation. Four of the teachers have been in the project since the beginning; the rest joined it this year; also from last year, three teachers have left as well as one University researcher (another one joined the project this year).

An overview of the four components

The first three components (Household Ethnographic Analysis; Teacher-Researcher Study Groups; Classroom Implementation) are adapted from the prior project—Funds of Knowledge for Teaching. I, as well as others, have presented these elsewhere (Civil, 1993; 1995c; González, 1995; Moll, Amanti, Neff, & González, 1992). Thus, rather than going over the structure, I will just give some highlights and pose some questions based on our most current work.

Household Visits

The project teachers receive training in ethnographic research methods. They then visit the homes of some of their students to learn about the funds of knowledge in these households. Questionnaires on the family structure, parental attitudes towards child-rearing, labor history, and household activities are used to provide some structure to these home visits. These questionnaires include several questions aimed at uncovering the mathematical potential in the households. A key effect of these household visits is on the teachers’ perceptions of their students. By seeing and learning about their students’ experiences, they develop a firsthand understanding of such experiences, as opposed to being told generalities about the “minority culture.” In a recent Study Group session, one of the teachers was describing her household visit. As she talked, I was drawn to this family and started feeling their struggles as well as the richness that this teacher had felt in her visit. As we discussed her visit, one of the teachers, who had recently joined the project, asked “how do you make the curriculum out of the home visits?” This, and similar questions, such as “how can visiting only one family help develop a theme for the whole class?” are questions that have been raised before and that I am constantly wondering about. As a mathematics educator, as much as I enjoy the wealth of information that comes out of these household visits, I find myself constantly wondering about connections to the teaching of mathematics in school. The teacher who was describing her household visit replied that the effects couldn’t be seen necessarily in specific events, but that it was more of a holistic effect. “Once you start the interview and open the door, there’s a lot that comes in,” she said. By visiting this family, she had gained a perspective of who her student was that she did not have before and she knew that she would be drawing on this newly gained perspective in her future interactions with the student. It was her own narrative account of this teacher’s household visit that most affected me and, I believe, the other study group members. This was very insightfully verbalized by one of the researchers, Marcia Brenden, who consequently put it in writing. Here is what she writes:

An issue that is central to the project’s approach to the household visits is the unlearning of normalized ways of seeing and documenting minority families. As C. outlined the single parent family she chose to interview, the profile could have been reduced statistically to a classic case of a family at risk: divorced,
Mexican American mother and father; unstable home life with frequent moves and family in and out of shelters; mother and children now live in low income apartment; ...; absent father with a history of substance abuse and violent behavior...

And yet, seeing this family in a personal way, ..., C. reports that she feels uplifted by the interactions, ... “they feel like a very rich family to me. They are not poor. They are very wealthy because of their togetherness.” What then is the ethnographic interpretation of the resources in this family? How and why does this interpretation differ in intent and content from a sociological tally of how far this family falls from the mythologized norm of two-parent, middle class, white American family?

The true product or “useable resource” that may result from this series of interviews is the qualitative interpretations of the strengths in this family. Spiritual resources are harder to document and perhaps less “useful” in curricular innovations than other types of resources. But what is most important is that a teacher has re-viewed a family that statistically could be written off as “in crisis” or “at risk” in order to document instead a single mother who exudes a positive and persevering response to life’s circumstances. This mother is understood to be a resource for her children and their education. ... A statistically “at risk” family has been revalued as “at promise.”

Though the products of the interviews are not always tangible curriculum units, the process of the interviews may lead a teacher to new ways of contextualizing statistically “at risk” families that defy the prevalent cynicism surrounding seemingly intractable social problems. In this way, teachers, students, and families are actively involved as agents in the reflexive constitution of the process of education.

Marcia Brenden, working paper, February 1998

This teacher’s experience is by no means new. In fact, this was clearly a strength of the previous project (see González, 1995, for teachers’ narratives on the impact of the household visits in the Funds of Knowledge for Teaching project). I am bringing it here because these are new teachers (in the sense that none of them were in the prior project) who joined BRIDGE because of an interest in the teaching of mathematics (where this interest takes many forms). In the Funds of Knowledge for Teaching project, mathematics was not the focus. Thus, the impact of household visits could take different forms in terms of curriculum implications. In BRIDGE, these implications should be in the area of mathematics, or so I thought. But in listening to the teachers talk about their household visits, I realize that these visits provide the teachers with enriched images of what some of their students’ families are like. They provide a human connection that has clear affective impact on the teacher.

One teacher chose as the family to interview, the family of a boy who is quite good mathematically, but a rather poor reader and writer. He was intrigued by this difference and wanted to learn more about who this child is. He found his visit to the family an eye-opener. The father works in construction and this boy participates and is knowledgeable about his father’s work. From the household interview, he learned that the child has many opportunities for mathematics explorations around the theme of construction. He also thinks that this boy developed many of his math skills because of a great interest in money: he goes to the swap meet and then has ‘business’ transactions at school. He also thought that because both his family and the teacher
consider that math is important, he gives 100% performance in math. As he presented his findings to the rest of the study group participants, they gave him several suggestions on how to work on this student’s reading and writing while building on his business interests. This is an important aspect of the study group dynamics—the creation of a professional support group.

Another teacher, when interviewed shortly after her first household visits, said:

> It has allowed me to think about ways to involve parents in a different way. Literally involve the parents. [She then describes how one parent drew the plans for how to build a burner for a hot air balloon, a theme she was exploring with her students].
> As far as [the household visits] impacting my teaching (...) first is has to impact my thinking and then at some point it will impact my teaching. (Teacher’s interview #1)

And maybe this is the biggest contribution from these household visits: they are impacting teachers’ thinking and the images about who their students are.

**Classroom Implementation**

Originally, the idea was that the findings from the household visits would be discussed and analyzed in the study group sessions and curriculum units would be then planned and tried according to the different teachers’ interests and circumstances. How does this translate when mathematics is the focus? To which extent can we expect teachers to focus their energy on mathematics, when they have to teach so many other subjects? This is something that one of the teachers, who is particularly engaged in the project, keeps reminding me of “Marta, I do have to teach things other than math.” This teacher has developed a curriculum project around a garden theme. I cannot even begin to describe how much time, energy, and resources she has spent on this theme—not only concerning the mathematical content associated with a garden theme, but developing the garden, going on weekends and holidays to school to water the plants, covering them to protect them from cold weather, going to local gardening resource centers to gather information, etc.

This garden theme has provided not only a context for the students to learn mathematical concepts such as measurement and graphing (e.g., height of plants); area (e.g., of the garden); volume (e.g., amount of soil), but has also served as an opportunity for the development of a new community in the classroom, one that brings together students, teacher and parents. The mathematical explorations grounded on the garden theme led students and teacher to explore problems such as maximizing area, given a fixed amount of fencing, or the need for a scale in graphing the height of a plant. These problems are contextualized in the students’ experiences with their gardens, but are then pushed in several directions to expand the inquiry process, all the while keeping in sight the curriculum of district required mathematics.

An interesting aspect of this project is the teacher’s own learning of mathematics. This project has taken her into uncharted territory; she has been spending more time than she used to in the teaching of mathematics, and more specifically exploring geometry and measurement, much more than she had done in the past. This is a confident teacher who is aware of her knowledge and understanding of mathematics and is eager to learn
I feel like sometimes I’m limited in my own knowledge as far as what I want to do mathematically. And so, I have to go to books and say, “now, is that really what I want to go with my 4th and 5th graders? Or do I want to go in that direction? And would this be considered rigorous math? And will it work when my kids get tested on [a district standardized test]? Will they have learned something that will transfer over?” And that’s threatening, really threatening. (teacher’s interview #2)

To which extent are the teacher’s own understanding of and beliefs about mathematics key players in the process? For example, one of the most successful curriculum projects (from the point of view of engaging students in challenging mathematics, students who at the beginning of the year had shown no interest in the subject) was developed by a teacher/researcher who, besides being a very experienced teacher, has a background in mathematics and civil engineering. He is an skilled draftsman who was able to combine his knowledge and experiences with the interests and knowledge of this students (uncovered through informal interviews) to produce a solid architectural curriculum unit that engaged these middle school students in the study of the district required mathematics (and beyond).

Thus, in summary, the classroom implementation component takes different aspects depending on the teacher and his/her circumstances and interests. For example, one teacher is particularly interested in looking at mathematical discourse in her classroom and working on ways to engage students in mathematical discussions that may resemble what “mathematicians do.” When in one of the Study Group sessions we discussed the article by Lampert (1990), she commented that she was really glad to have read this article because it corroborated many of the things she believed in and made her feel better in that she thought she was already doing some of what the article describes in her own teaching of mathematics. For example, she encouraged students’ building of concepts and vocabulary in mathematics by prompting elaboration of their answers and reasoning. We have since then videotaped this teacher three times with the goal of engaging in a dialogue with her to find out how she views herself as a teacher of mathematics, her use of discourse, and her interpretation of how it relates to Lampert’s article. For this teacher, the ethnographic aspect of the household visits is very important to the process of changing her teaching. The visits give her a personal connection that she believes she will be able to use to engage students in the discussion of mathematics.

Two other teachers work in a school district that has adopted an innovative, reform-oriented mathematics curriculum. It is a demanding curriculum for both teachers and students. Thus, we are also looking at ways to mesh the project goals with these teachers’ needs. We think that the curriculum has a lot in common with our goals, in particular, in terms of giving students challenging tasks and using an inquiry-based instructional approach. But the truth is that this is new curriculum for these teachers, and we feel that our priority is right now on supporting them as they use this curriculum by, in the study groups, exploring mathematical topics that tie to what they are expected to teach.

Yet, another teacher, who recently joined the project, is teaching middle school students who seem to have “no interest in being there.” By her own initiative, she started contacting family members of some of her students to try to understand how to better reach them academically. BRIDGE gives her an arena to raise and explore her issues and concerns.
Parents as Learning Resources

One of the outcomes of the Funds of Knowledge for Teaching project was a redefinition of parental involvement on the part of many of the teachers in the project. The household visits provided them with an array of possibilities. Parents (and other family members) became resources who, for example, would come to the classroom and share their experiences and expertise on a variety of topics. This is still the case with one of our teachers. For her garden theme, she has had parents actively involved in a variety of ways. She even finally met the parents of one of her students who came to see their son’s large production of tomato plants. This was the first time that these parents had come to their son’s school.

But, as we prepared for project BRIDGE, we wanted to do something else with parents. For one thing, because mathematics is the focus in our project, we want to better document the uses of mathematics by working class, minority adults in our local community. This has turned out to be a very hard “exercise.” For example, what are the implications of noticing that a seamstress makes a quarter of a circle by holding her measuring tape fixed at one corner of her rectangle (the center) and marking points 25 cm from that point, then joining them to get her quarter circle?

It certainly shows the circle as the geometric locus of points equidistant from a given point. But how can we use her knowledge to inform us for school mathematics? At the level of the study group, uncovering and analyzing the mathematics embedded in the practice is very important to our professional development goals (González, Civil, Andrade, & Fonseca, 1997).

These discussions give us a context to explore mathematics, and to talk about our beliefs and values about what we count as “valid” mathematics. But, at least in my case, I am aware that my own training in “formal” or “academic” mathematics limits my analysis. Miller’s (1992) paradox rings true in our work: “How can anyone who is schooled in conventional Western mathematics “see” any form of mathematics other than that which resembles the conventional mathematics with which she is familiar?” (p. 11)

Not knowing about the practices themselves is perhaps the main problem (this became evident to me in a recent discussion on carpet and tile laying). Thus, we want to continue our research on the “everyday mathematics” to gain a better understanding of the various forms and places in which mathematics occurs. We are doing this by interviewing adults in the community. José David Fonseca, teacher-researcher in the project, has done a set of initial interviews. To this date he has interviewed a seamstress (different from the one I referred to earlier), a mechanic, a tile layer, a designer, and a construction worker. The analysis of these interviews is still ongoing. In the analysis we are looking at mathematical content and dispositions (e.g., persistence; enjoyment of challenge). Through these interviews we are also learning about these parents’ values about their “own” mathematics and about their expectations for their children. Generally speaking, these parents appear to be very confident about their knowledge of their practice, but they seem to dismiss this knowledge as if there was nothing to it. However, this is still a one-sided approach: we have not yet engaged in a discussion of mathematics with the adults in question (Vithal & Skovsmose, 1997). This is what we hope to do in the other
component of our work with parents.

The other aspect of our work with parents is the development of a core group of parents to engage in a two-way dialogue about the teaching and learning of mathematics. Eventually, we would like to have small core groups in all the schools we work in. But the logistics of getting such a project going have been quite complex (Andrade, working paper, 1998). We are currently working with a core group of working class, immigrant, Spanish speaking mothers. Through regular workshops, we explore these women's ideas about and understanding of mathematics, while maintaining a two-way conversation to better inform our work with their children. In many ways, these workshops reflect our approach to professional development for teachers. Thus, we select reform-based activities and have them work in small groups, constantly encouraging them to come up with their own approaches. This provides a very rich environment for us to learn about their thinking about mathematics.

The discussions have shown a mixture of wanting to do things the way they were taught (although sometimes they only remember part of the procedure) and a common sense, practical approach (as in the case of trying to go from a recipe for eight people to one for four people, where one of the proposals was to bake the one for eight and either freeze the leftovers or give them away). All throughout, these discussions have shown an eagerness to investigate, to learn. For many of them, the approach is different from what they experienced in their own schooling—a traditional approach in which they were shown (told) how to do things. Thus, a question that we have is how do these women appreciate an open-ended approach in which closure (in a traditional sense) is not necessarily reached at the end of each individual workshop? Another question we have is should we be looking at, for example, fractions from the school mathematics point of view in these parents' workshops? We want to do this because one of our goals (and one of the reasons why these women expressed an interest in participating) is for them to be able to help their children at home with school mathematics. However, we wonder about how to bring in school mathematics in ways that make it relevant to these adults, not “only” as mothers, but as learners themselves.

We want for these parents to be seen as intellectual resources in that not only they participate in the discussions but then they go to classrooms to teach what they are learning in these workshops. This is a different kind of parental involvement from what many minority, working-class parents usually experience (e.g., monitoring of cafeteria, organizing papers for a teacher, cutting things for an arts activity, ...). To better describe our intent in the work with parents, I will quote Andrade:

Sarason (1994) has called for engaging the minds, hearts and voices of parents, students and teachers alike, if collaboration is to take place. This work of facilitating partnerships is complex, requiring a great many resources and reflection. Further, it is not mechanistic, for it requires taking each of the interactants into account. As Sarason has suggested, it is about engaging minds, hearts and voices. But above all, it is about the unspoken eloquence of humility, where everyone comes to learn, no one better than the other. (Andrade, Working Paper, January 1998)

Study Groups

The Study Groups are the key component to this project in that here is where we (teacher-researchers and
university-based researchers) all come together to discuss the different aspects of our work. We meet every two weeks, for about two hours, in alternating schools. The content of the Study Group sessions has been quite varied. Some of the sessions centered on debriefing the household visits; others engaged us in explorations of mathematics. These explorations in mathematics are largely grounded on the teachers' interests and needs. For example, in the case of the teacher who developed the garden project, the fact that her students had to change the shape of their group gardens to maximize area, led us to a hands-on exploration of area, perimeter, and volume and how the scale factor affects each of these. The fact that most of the teachers in the project have to teach "fractions" has led us to a discussion of teaching of fractions (based on teaching cases). Yet, more recently, some of these explorations have reflected our attempt to uncover the mathematics in everyday practices, as explained earlier (e.g., the work of a seamstress, or using Masingila's (1994) article as a basis for a discussion on the mathematics of carpet and tile laying). Other study group sessions center around discussion of relevant articles on research on everyday cognition and mathematics, ethnomathematics, culture and mathematics, language and mathematics, and inquiry-based approaches to mathematics education.

The dynamics of the study group sessions are constantly changing, in part due to the changes in participation that I referred to earlier in the paper. We seem to have now reached a working model, by which we all take turns in facilitating the different sessions. Our more recent sessions have revolved around the issue of social vs. individual construction of knowledge in mathematics. We are still exploring this, and what I have to offer is very tentative, but I want to do so to give a flavor for what one study group session may be like. (Note: in what follows I am paraphrasing from the transcript of one recent study group session, in an attempt to give the gist of the discussion.)

Our discussion centered on the question of whether in our project, we are conceptualizing learning as a sociocultural activity or as individual cognition. The notion of "level" emerged from different angles. One teacher replied that this issue (learning through interaction or individually) would depend in part on the level of difficulty of the task. Another teacher then brought up the notion of there being different levels of mathematics, as she referred to the fact that she had met unschooled people in Mexico who were very good at basic mathematics through their work experience. This in turn brought up the questions of, if there are these levels of mathematics, is what we are doing BRIDGE only going to address the very basic mathematics? Are we not going to get into the more abstract mathematics? This is certainly a concern that several of us share and that I have brought up elsewhere (Civil, 1995a, 1995b). One of the study group members asked "is there necessarily a relation between the experiences with [everyday] mathematics and school mathematics? If you have too much school mathematics, does it erase our practical mathematics?" To this, I responded:

I don't think that I could learn how to build a building [this comes from an earlier part of the discussion in which we were talking about the mathematics embedded in construction]. I don't know if I saw these people and interacted with them, I don't know. But I think that at this point, I already bring, on the one hand my preconceived notions of how bad I am at building things. But also, my knowledge of mathematics would influence my approach. For example [going back to Masingila's article] on finding the line in the middle of the room, I bet I would think about it in terms of school geometry, measuring, finding the bisector, etc. Maybe that is not the most efficient way of doing it, but I would only be able to bring
that to it. You were saying something about basic mathematics, and I am not sure about this, I am not sure about this notion of levels; it goes back to Abreu's discussion on values. So going back to the question of “is BRIDGE only addressing basic mathematics?” The problem is how to bring the different mathematics together and we at the same time not thinking that there is less value on the kids doing activities like the gardening. When you try to bring it into the classroom and have a discussion about the perimeter and area, you start losing kids; they get disengaged. I am not sure it is because the mathematics is more abstract. I don't know what it is really. I don't deny there are different levels of knowledge, but I am not sure one is higher than another. I am struggling with this issue constantly in my own teaching. For example in the Freshman level class I teach, we were working on tessellations. They were making patterns, putting things together, but as soon as I tried to get them to look at the mathematics in all this, most of them did not seem interested in knowing why the regular pentagon does not tessellate, while the regular hexagon does. [Study Group – Transcription]

In Closing

In closing this paper, I would like to bring up three issues related to the Study Groups that come to mind as I reflect on our work in the project.

1) What about our funds of knowledge? One of the goals of the project is to uncover families’ funds of knowledge. Yet, as Marcia Brenden noticed recently as she talked to one of the teachers and found out about his interest and knowledge about astronomy, we have not worked on uncovering the teachers’ funds of knowledge. In fact, I would add, we have not discussed our own funds of knowledge, of each of us in the group. This not sharing “who we are”, “what we know” has, I think, direct implications on the dynamics of the study group sessions, as we may be tempted to bring in prior experiences and expectations about professional development projects.

2) Issue of authority. In the beginning, the study group meetings were run by University staff. Again, this conforms to the model that many of us may have experienced in other professional development programs. The facilitating of the meetings has now moved to a point where it rotates among the different members. But there is still an issue of ownership. We have been trying to address the question of “what do you want to get out of these meetings?” “How do you want them to function?” I think that some teachers still do not feel like they “own” the project and are not sure whether they want to facilitate a meeting. Of course, the fact that some teachers leave the project and others come in, make it harder to develop a sense of continuity. It is not like other projects I have had experience with, in which teacher attrition does not affect the content, because we (the staff) provide the activities, the teaching, the discussion questions, etc. In BRIDGE, we are co-dependent. We are carrying out a conversation. Can newcomers catch up?

3) Theory and Practice. In the Study Group meetings, we sometimes engage in what could be considered more practice focused sessions (e.g., exploring classroom activities on fractions). At other times, we focus more on theoretical discussions around the work that we are doing. An example of this may be the recent discussion (illustrated earlier) on learning as individual cognition or as a sociocultural activity. Some of the participants
want more practice focused sessions. Others, enjoy the theoretical discussions. As one teacher remarked, reading a given article for the third time was the breakthrough for her: she made connections between her practice and the theoretical framework laid out in the article. We are striving, I think, for these connections, but trying to keep the balance between theory and practice is often a challenge when we factor in all the different pressures and needs that the different project participants have (e.g., for teachers it may be the district assessments that they have to give: they want suggestions on how to prepare students for those, or just suggestions that they perceive as relevant to their everyday teaching; for university based researchers, it may be related to the fact that we come from different disciplines and thus may have different expectations and kinds of pressures that affect what we would like to see happening in the study group sessions).

References


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CONCEPTUAL CHANGE IN SCIENCE TEACHING AND TEACHER EDUCATION

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Introduction

Conceptual change is catching on. In an elementary classroom, students argue about whether or not a table pushes up on a book it is supporting. In a secondary classroom, students produce their own models of genetic inheritance and try to persuade others of the viability of their ideas. In a science teacher education program, prospective elementary teachers make observations of the moon over an extended period and use sun-earth-moon models to explain their observations. In a graduate class, teachers talk about interviewing their students and encouraging them to express their ideas in class. At professional conferences educators present papers on using conceptual change ideas at elementary, secondary, and tertiary levels. These are current examples of events in which educators are trying to understand what conceptual change is and what it means for science education.

But what is conceptual change? A popular slogan for the latest fad that will leave the educational world unchanged as have so many earlier ones? Or an idea that has the possibility of transforming science education for the better? Initially the idea of conceptual change was used in education as a way of thinking about the learning of disciplinary content such as physics (Posner, Strike, Hewson, & Gertzog, 1982) and biology (Carey, 1985). Its use, however, has expanded in two ways. First, from the outset the notion of teaching for conceptual change has gone hand in hand with considerations of learning as conceptual change. Second, conceptual change has been considered in other domains of disciplinary content such as chemistry, earth science, mathematics, writing, reading, and teacher education.

One organization that exemplifies the growth of conceptual change ideas in the past decade is a special interest group (or SIG) on conceptual change formed as part of the American Education Research Association (AERA). The SIG was started in 1983 in order to provide an annual meeting point for like-minded individuals within a huge organization. While AERA is very largely attended by Americans, from the outset the SIG’s membership has had more international members than Americans. This year’s SIG sessions included papers from authors in Australia, Brazil, Britain, Canada, Israel, Italy, South Africa, and the USA. In other words there is an international interest in conceptual change. Comparing conceptual change sessions sponsored by the SIG with those sponsored by others within AERA provides some indication of the growth of interest in conceptual change. In 1988 the AERA annual meeting had six sessions that listed “conceptual change” as a descriptor; 5 of these were...
sponsored by the SIG. The respective figures were 9 and 8 in 1990, 12 and 7 in 1991, and 15 and 7 in 1992. Thus, while SIG membership has hovered at around 200 for the last few years, interest in conceptual change has developed in areas other than science learning: sessions at AERA in 1992 also focused on conceptual change in mathematics, teacher education, reading, and writing.

Another indicator of the acceptance of conceptual change is its presence in documents about recent educational reform in Spain (D.C.B. 1989.) References to it include a consideration of “perspectives that view learning science as a conceptual change in the pupil’s cognitive structure.” (p.111) and a recognition that “[O]ne of the central objectives in teaching science is to promote changes in pupils’ conceptions . . . “ (p.159)

But what is conceptual change? To understand what it is and how it might influence science teaching, it is necessary, in my view, to consider its links to two other ideas that are currently popular. These are constructivism (as a view of how people learn) and students’ conceptions (tenacious ideas different from those generally accepted and held by students of all ages in all countries, called among other things alternative conceptions or misconceptions). In this article I shall first consider different interpretations of the idea of conceptual change. I shall then outline with reasons what I understand conceptual change to be and explore its links to constructivism and student conceptions research. Finally I shall consider different implications that conceptual change might have for learning and teaching in both science and science teacher education.

**Interpretations of Conceptual Change**

When thinking of conceptual change it is helpful to recognize that the word “change” is used in different ways. One might talk, as in the fairy tale, of a princess kissing a frog who, as a consequence, changes into a prince. In this case there is only one entity before and a different one after the change; the frog is no more; there is only a prince. Here change means extinction of the former state. A second example might be an election for political office with the incumbent being beaten by the challenger: there has been a change of mayor. Both people continue to live in the city, but only one person is mayor. The incumbent loses status, while the challenger gains it. In this case, there is no extinction; change means an exchange of one entity for another. A third example might be a home that started as a small four-roomed cottage early last century, and was later extended by adding a wing at either end. When water and light became available, a bathroom and a kitchen were attached. It is still the same home: change here means extension.
Interest in conceptual change has, to a considerable degree, been focused on the problem of students who hold one view ("a table supports a book by being in the way") in contrast to the canonical view ("a table supports a book by exerting an upward force on it.") How should one characterize a student who changes his or her mind from the former to the latter? Change as in the first example above—extinction—does not seem to be an appropriate characterization of this change. There is no sense in which one view has disappeared to be replaced by the other; students, by and large, will remember both views and simply say: "I changed my mind" or "It made more sense." Change as in the second example—exchange—seems a much better characterization of what the student has reported. It is change of this kind that is evoked for most people on hearing the term "conceptual change." I have referred to this elsewhere as "conceptual exchange." (Hewson, 1981)

In the literature on conceptual change different interpretations of related concepts have emerged. It is helpful to consider these in the context of the change examples discussed above.

**Conceptual Change: Inclusive or Exclusive?**

One set of interpretations of conceptual change is closely related to the growth of an awareness of the diversity and tenacity of students' views of natural phenomena. Thus when one thinks of a student learning ideas that are the goals of a given curriculum, one needs to consider whether in order to achieve a goal the student may have to give up, reject, or demote an idea particularly if it contradicts the goal idea. Such a case would entail conceptual exchange, and there is common agreement in the literature that the process of a student exchanging one idea for another is conceptual change.

For some, this is all that conceptual change means. It is thus a term applying to the problematic part of a person's experience of learning—giving up one idea for another—but by inference does not apply to learning that is not problematic. In other words, for some people conceptual change is exclusively conceptual exchange. Others, however, see sufficient similarities between problematic and unproblematic learning to think of conceptual change as including different types of learning. For example, in both cases a person goes from not knowing an idea to knowing it. This is where change as extension is a useful metaphor in thinking about learning without difficulty. Here, students learn things they didn't know by making connections to what they already know; this is not a problem when their present views can be reconciled with what they learn. Another way to think about this is to regard existing knowledge as "capturing" new knowledge (Hewson, 1981). From this perspective, conceptual
change is an inclusive term, including both exchange and extension (or capture).

Knowledge: Relative or Right/wrong?

Some alternative interpretations of conceptual change derive from alternative views of the nature of knowledge, e.g., the nature of physics knowledge. One view is that the adequacy of a set of ideas, e.g., Newton's laws of motion, depends on the context in which that set is used. While there is an incredibly wide range of phenomena that are well described by Newton's laws--planetary motion, the building of bridges, and Brownian motion all come to mind--they are less than adequate when dealing with the very fast (where relativity becomes necessary) and the very small (where quantum mechanics takes over), and they provide explanations of common, everyday events such as throwing a ball and a table supporting a book that are counter-intuitive to a large proportion of the general public. This suggests that the context in which knowledge is used needs to be considered, and thus that different viewpoints can be seen as alternative conceptions rather than one having to be right and another wrong.

An alternative view of the nature of knowledge, particularly scientific knowledge, is that its growth represents a progression towards truths about the natural world. In other words, science discovers aspects of the world as it really is. It is, as a consequence, always possible to decide in principle whether a particular view of an event or phenomenon is right or wrong. Additionally this view focuses attention more on scientific products ("the facts") than on how this knowledge was produced. This suggests that views in opposition to what is right should be labelled misconceptions and thus conceptual change means replacing misconceptions with correct conceptions.

Conceptual Change: Teaching and/or Learning?

A third set of interpretations of conceptual change revolves around the relationship between learning and teaching. It seems inevitable that issues of teaching will arise when learning is considered: the concept of teaching has little meaning without the concept of learning. In what follows, I find it useful to differentiate learning activities from learning outcomes.

One perspective on the issue is that teaching causes learning; if no learning occurred, then you couldn't have been teaching. Possible consequences of this are a blurring of the distinction between teaching and learning--some teachers use the terms interchangeably or in combination, e.g., teaching/learning--and a focusing on teaching strategies at the expense of learning activities because of the implied assumption that "if I taught well,
my students will have learned what I wanted them to.”

An alternative perspective (Hewson & Hewson, 1988) sees the relationship between teaching and learning in a different light. While teachers may require their students to carry out learning activities and intend that these will lead to particular learning outcomes, it is also necessary that learners share these intentions. In this view, then, teaching is not a cause of learning outcomes; it facilitates them. Thus teaching can take place without learning occurring and vice versa. Possible consequences of this are a sharpening of the distinction between teaching and learning and a focusing of attention on learners and what is involved when they achieve intended learning outcomes.

Examples.

Papers delivered at recent conferences of educational organizations (NARST, AERA) in the USA provide examples of some of these different interpretations of conceptual change. Westbrook & Rogers (1992, p.3) stated that the process of using “strategies to bring children’s thinking into line with that of scientists... has become known as conceptual change.” Here conceptual change is explicitly identified as a set of teaching strategies with the added implications that conceptual change is exclusively exchange and children’s views are wrong while scientists’ views are right. Another example comes from Stofflett (1992, p.3) who writes that “research on scientists’ cognition identifies the process of conceptual change as a necessary prerequisite for the formation of scientifically validated theories.” The focus here is on learning rather than teaching, a sense that the basis for validating theories is important (rather than that scientists are right.) In a third example Tobin (1992, p.2) states that “[c]onceptual change is learning, which is a social process of making sense of experience in terms of extant knowledge... Since all learning occurs in a social milieu, all learning is inherently social... Accordingly, all conceptual change must be considered in a socio-cultural context.” For Tobin, then, conceptual change is an inclusive idea, knowledge is relative to the context, and it is firmly a learning issue.

My view of Conceptual Change

Constructivism.

The general approach that I adopt is a variation of a constructivist perspective (Magoon, 1977). This assumes that humans construct their own knowledge, using their existing knowledge in order to do so. This
construction of knowledge takes place within a context of social interaction and agreement. In the process of construction, people develop relatively stable patterns of belief. They construct knowledge in ways that to them are coherent and useful. Since the construction process, however, is influenced by a variety of social experiences, the knowledge constructed by each individual is not normally completely personal and idiosyncratic. Further, I believe individuals are boundedly rational (Shulman & Carey, 1984; Simon, 1982). Existing knowledge and social agreements about meaning not only limit how new experiences are interpreted, but also influence what is perceived in any situation. Thus, two individuals exposed to the same events may perceive and interpret them in very different ways, depending on their individual underlying knowledge and beliefs and the ways in which these beliefs influence and are influenced by the social interactions out of which they are formed. Part of the evidence to support this view comes from studies of students' conceptions such as those referenced below. It is of interest that references to constructivism appear in the goals of recent educational reform in Spain (D.C.B. 1989): "School must ensure the construction of meaningful learnings . . " (p.33) and in statements about the nature of "the pupil who . . . constructs, modifies, and coordinates her or his schemata . . " (p.34).

**Students' Conceptions of Natural Phenomena.**

In recent years, many studies of students' conceptions of natural phenomena have been carried out in different disciplines, in different countries and at all educational levels from elementary school through college graduates. The research has been reviewed in articles (Driver & Erickson, 1983; McDermott, 1984), conference reports (Heim & Novak, 1983; Novak, 1987), books (Driver, Guesne, & Tiberghien, 1985; Osborne & Freyberg, 1985), and bibliographies (Carmichael, et al., 1990; Pfundt & Duit, 1991.)

The constructivist perspective leads to an interpretation of many of the observed regularities and consistencies in students' responses as alternative conceptions that students hold about the natural world and how it works. Two notable characteristics of alternative conceptions are that they are often significantly different from, and thus alternative to, generally accepted views of the subject, i.e., they conflict with ideas teachers want students to learn; and they are surprisingly resistant to change as a result of traditional instruction (Champagne, Klopfer, & Gunstone, 1982.) Thus even when as is generally the case, students' alternative views are not as precise, not as extensive, not as widely useful as those that teachers want students to learn, it is their tenacity in the face of instruction to the contrary that point to the need to design instruction that acknowledges students' alternative
views and does so in an environment in which students accept that their own ideas may from time to time be the object of study.

**The Conceptual Change Model.**

The interpretation of student responses as driven by alternative conceptions suggests that learning may involve changing a person's conceptions in addition to adding new knowledge to what is already there. This view was developed into a model of learning as conceptual change (or CCM) by Posner, Strike, Hewson, and Gertzog (1982) and expanded by Hewson (1981, 1982). From this point of view, learning involves an interaction between new and existing conceptions with the outcome being dependent on the nature of the interaction. There are two major components to the CCM. The first of these components is the conditions that need to be met (or no longer met) in order for a person to experience conceptual change. The extent to which the conception meets these three conditions is termed the status of a person's conception. The more conditions that a conception meets, the higher is its status.

The second component is the person's conceptual ecology that provides the context in which the conceptual change occurs, that influences the change, and gives it meaning. The conceptual ecology consists of many different kinds of knowledge, the most important of which may be epistemological commitments (e.g. to consistency or generalizability), metaphysical beliefs about the world (e.g. the nature of time), and analogies and metaphors that might serve to structure new information.

Learners use their existing knowledge (i.e. their conceptual ecology), to determine whether different conditions are met, that is whether a new conception is intelligible (knowing what it means), plausible (believing it to be true), and fruitful (finding it useful). If the new conception is all three, learning proceeds without difficulty. The metaphor of change as extension is helpful in understanding this by drawing attention to the need for new additions to fit coherently into an overall plan. Just as an extended house is enhanced by additions that are well thought out and consistent with the existing structure, so too will be a conception that is extended. For example, a conception of acceleration that includes a definition as rate of change of velocity is enhanced with the inclusion of methods for measuring acceleration, examples of acceleration, the important role of acceleration in Newton's second law of motion, and so on. If, however, the new conception conflicts with existing conceptions, then it cannot become plausible or fruitful until the learner becomes dissatisfied with the old conceptions. In that event,
learning requires that existing conceptions be restructured or even exchanged for the new. The linked changes of status in the metaphor of change as exchange provide one way of thinking about this process. The relationship between status change and conceptual change is examined more fully elsewhere (Hewson & Hennessey, 1991.)

A central prediction of the CCM is that conceptual changes do not occur without concomitant changes in the relative status of changing conceptions. Learning a new conception means that its status rises, i.e., the learner understands it, accepts it, sees that it is useful. If the new conception conflicts with an existing conception, i.e., one that already has high status for the learner, it cannot be accepted until the status of the existing conception is lowered. This only happens, according to the CCM, if the learner holding the conception has reason to be dissatisfied with it. The learner's conceptual ecology plays a critical role in determining the status of a conception because, amongst other things, it provides the criteria in terms of which he or she decides whether a given condition is (or isn't) met. In this regard, the person's epistemological commitments, e.g., to generalizability (Hewson & Hewson, 1984), are particularly important.

**Conceptual Change.**

What then, in my view, is conceptual change? For many people the term refers only to instances of conceptual exchange. But I would argue the value of including conceptual extension with conceptual exchange, because it draws attention to the status considerations that influence all learning, not just conceptual exchange. I also see conceptual change as primarily a way of thinking about learning, i.e., it is something that a learner does as an intentional act, rather than something done by a teacher. There is, of course, much that a teacher can do to facilitate a student's learning, without any need to regard this as a mechanistic, causal process. Finally, it seems to me that the knowledge a learner gains only has validity in terms of, and is thus relative to, his or her conceptual ecology. Since a learner's conceptual ecology is a product of all the experiences and social interactions he or she has had, it will have many elements in common with those of other people.

This means that a curriculum should include not only particular theories and attendant phenomena, but also the basis for their acceptance. If we can't justify curriculum content to students, we shouldn't teach it. In other words, we need to recognize that “alternative” is not a synonym for “inadequate” or “unacceptable”. The purpose of conceptual change teaching of science is not to force students to surrender their alternative concepts to the teacher's or scientist's conceptions but, rather, to help students both form the habit of challenging one idea...
with another, and develop appropriate strategies for having alternative conceptions compete with one another for acceptance.

**Implications of Conceptual Change for Science Education**

In light of the above, it is possible to think about conceptual change entering science education in at least four ways. These four issues have to do with learning science, teaching science, learning how to teach science, and teaching how to teach science.

**Learning Science**

As mentioned above, the research literature has shown that students come to their science classrooms with a range of different conceptions of the natural world surrounding them (Pfundt & Duit, 1991; Carmichael, et al., 1990). These conceptions vary greatly with respect to such characteristics as clarity, breadth, coherence, ambiguity, and tenacity. In particular, many of these conceptions are at variance with the currently accepted scientific view. The significance of this research lies in the fact that these are the ideas that students use when they are introduced to normal scientific content. Thus their learning of this new content is influenced by their current ideas, in ways that may hinder or may help their learning. It therefore is useful to think of learning the desired outcomes as a process of conceptual change, including both extension and exchange.

**Teaching Science**

Accepting that students hold different conceptions that might need to change is one thing: concluding that it is the teacher's responsibility to engage in teaching practices that might facilitate conceptual change to occur is a separate matter. While some might argue for a separation of responsibilities--teachers present the content and students learn it--it is not a position I advocate. On the contrary, I believe it is the teacher's responsibility to be aware of students' conceptions and to teach in ways that are likely to facilitate conceptual change on the part of the students.

Many teaching studies in recent years have attempted to take into account research on students' conceptions of natural phenomena. A number of different features have begun to emerge from these studies as character-
istic components of what can be called conceptual change teaching (Hewson, 1991). On one hand there are different stages in conceptual change teaching. These include:

- **Diagnosis or Elicitation.** Does the teacher use any diagnostic techniques to elicit students' existing conceptions and reasons why they are held?
- **Status Change.** Does the teacher use strategies designed to help students lower the status of existing, problematic knowledge, and raise the status of other, competing ideas? Are there other application sites where the new conception can be used?
- **Evidence of outcome.** Is there evidence that students' learning outcomes are based, in part, on an explicit consideration of their prior knowledge?

On the other hand, there are particular features that are present during different stages of conceptual change teaching. These include:

- **Metacognition.** Are students encouraged or able to “step back” from one or more ideas held by themselves or others in order to think about them and express an opinion about them?
- **Classroom Climate.** Is there an attitude of respect by both teacher and students for the ideas of others, even when they are contradictory?
- **Role of Teacher.** Is the teacher able to provide opportunities for students to express themselves without fear of ridicule, and to ensure that he or she is not the sole arbiter of what counts as an acceptable idea in the classroom?
- **Role of Learner.** Are students willing to take responsibility for their own learning, to acknowledge others' ideas, and to change their views when another seems more viable to them? Can students monitor their own learning?

Teaching that has included components such as these has been successful in helping elementary, middle school, high school, and college students change in significant ways their conceptions in content areas in many different areas in physics, chemistry, biology, and earth science. Bibliographies of these and related studies are available (Pfundt & Duit, 1991; Carmichael, et al., 1990.)

**Learning how to Teach Science**

I would argue that, just as students develop conceptions of everyday events, prospective teachers can
similarly be expected to develop conceptions of teaching based on their own experiences as students in many different classrooms, from courses in teacher education programs, and as student teachers. Thus, they can be expected to build conceptual structures in which they incorporate classroom events, instructional concepts, socially accepted behaviors, and explanatory patterns. These structures include, possibly implicitly on the one hand, their rationale for teaching and their view of knowledge, learning, and science, their disciplinary knowledge, and on the other hand the ways in which they teach, along with detailed specific information on content, students, school procedures, etc. I call this a conception of teaching science (Hewson & Hewson, 1988.)

It seems obvious to me that teachers' knowledge, skills, and attitudes are likely to be very different in kind, serving different purposes, and not necessarily being coherent. In other words, I find it reasonable to infer that prospective teachers will enter a program with their own individual conceptions of what it means to teach science that could differ in significant ways from those that are important to the program. Thus, similarly to the science learning issue above, I would expect that student teachers may need to undergo conceptual change with respect to their conceptions of teaching science that rest, often implicitly, on their conceptions of the nature of knowledge, of science, and of learning.

In order to identify the characteristics of a conception of teaching science appropriate for conceptual change teaching, Hewson & Hewson (1988) reviewed research on students' conceptions of natural phenomena, conceptual change science teaching, and teacher thinking. They concluded that science teachers should:

- know the phenomena, the methods, and the concepts, principles, and theories that constitute the science they are teaching;
- know what conceptions their students hold about the units to be taught, and the extent to which they are scientifically acceptable;
- be aware of the role played by students' existing knowledge in understanding new material;
- be convinced of the need to use conceptual change teaching strategies particularly when students' existing conceptions conflict with those being taught; and
- be able to plan and perform teaching actions that give effect to these strategies.

Teaching how to Teach Science

Finally, conceptual change enters science education through consideration of the strategies used by pro-
gram instructors to help prospective teachers undergo the desired changes in their conceptions of teaching science. Once again, in comparison with the science teaching considered above, the issue of how the responsibility for undergoing conceptual change is to be shared between prospective teachers and the program instructor becomes a significant one. In my view, it is the instructor's responsibility to use methods in teacher education similar to those being advocated for science teaching. In this case, these would be conceptual change teaching methods. This belief stems partly from the need for a program to be consistent in its methods and content, and partly because modelling particular teaching approaches is an especially effective way of making them accessible to prospective teachers.

There are clearly different ways in which a teacher education program can implement conceptual change issues, depending on the context of each particular institution. Science teacher education programs that have documented their attempts to use conceptual change ideas in thinking about their program include Monash University in Australia (Gunstone & Northfield, 1992), the University of Utrecht in the Netherlands (Wubbels, et al., 1992), and the University of Utah (Stoddart & Stofflett, 1992) and the University of Wisconsin-Madison (Hewson, et al., 1992) in the USA.

**Conclusion**

The idea of conceptual change entered education as an analogy drawn from the history and philosophy of science that was helpful in understanding the difficulties people experience in changing from one explanatory framework to another. Conceptual change has, however, expanded considerably since then in my understanding of it, from a way of thinking about problematic learning in science to ways of thinking about other types of learning, about learning in domains other than science, and about teaching that facilitates conceptual change learning. It does so in ways that are coherent and complementary, that provide good explanations of many educational events, that continue to raise good questions about current practices, and that suggest fruitful ways of reorganizing these practices. For all these reasons, conceptual change is a powerful idea. It is no wonder to me that it is catching on.
Bibliography


CHAPTER 2
CRITICAL AND CREATIVE THINKING IN SCIENCE

Science is not just a collection of information about the natural world. Rather, science is a living enterprise involving a range of human activities all focused on finding out how the world we live in works and on applying this knowledge to serve our purposes in this world. The information that does pass under the name “science” is the product of these activities. Thinking is involved in all of these activities, and in doing them well, the thinking we do must, correspondingly, be done skilfully and well.

How does the framework for thinking we have introduced into the work play itself out in the enterprise of science? Is there any part of thinking that is distinctively “Scientific Thinking”? If so, what are its characteristics?

“The Scientific Method”

The most common answer to a second and third of these questions is often the same wording “Yes” and an account of what has been called “Scientific Method.” Scientific method, in its most general form, is a special methodology for gathering data to test hypotheses, usually about the causes of things. This methodology involves gathering observational data that is public and reproducible, and provides some basis for further verification and extension of possible causes. This data is often gathered through experimentation in which certain variables are controlled so that the data provided can be used to generalise rules or to test specific possible causes.

For example, to try to determine whether or not worms of a certain sort found in the soil of a garden have red and gray, two groups of gardeners have formed their deaths, so each group was performed in which similar groups had controlled the same food with the worms, and other groups were given the same diet without the worms. Since the variables were controlled—that is, the only thing that varied from one group to the other, as far as the experimenters knew, were the worms. When the data in the group that ate the diet with the worms died, and the others didn’t, the experimenters had observational data that supported the hypothesis that the worms were poisonous to these. How should, of course, be cautious about thinking that these data show conclusively that the worms are poisonous to these plants. If scientists said that these data showed that these worms were poisonous in all cases, this person would be mistaken, according to the criteria of scientific investigation. This is because, for all these investigations known, these worms, together with certain other organisms that are present in the digestive system of the type of garden soil, are involved in the deaths. To rule this out, another experiment of a different sort would have to be conducted. In fact, to be in a position to generalise from the data, we need to know certain things about the sample we are relying on, or articulating in scientific generalizations.

The thinking that scientists judge whether it is reasonable to think that these worms killed the bees based on the data in this experiment is, of course, critical thinking, and using the standards in science that relate to the need to make sure that all other variables are controlled in what makes this kind of judgment of causal explanation valid. But another important critical thinking skill must be involved as well; we must make sure that the observational reports we base our judgment on are accurate and reliable. Are the investigators in this experiment reliable judges of exactly what they observe in terms of harmonies? Are their reasons and the data collected from accurate and reasonable. To be sure that the data is considered in an accurate, a good scientific observer must still determine whether the data observation is a reliable source of this interpretation. Here, the standards that we use to determine the accuracy of an observation are obviously important to the making of judgment of scientific thinking as well.

Moreover, consider the other kinds of critical thinking that go into the gathering of data from such an experiment. Critical thinking not only involves the experimental and critical groups in some autonomy, clarifying the data that results...
making sure that the sequence of events in the experimental set-up involved decisions to some degree.

When we back up a bit and think about what kind of thinking goes into the process of designing an experiment of this sort, we realize that prior knowledge of what sort of results would show up or not against the hypothesis under consideration is quite essential. When we design such experiments, we are, in fact, thinking about what evidence we expect to find that would rule in or rule out the particular hypothesis and how we might gather that evidence. This involves us in more skilled thinking in that we are to design an experiment well. For example, we have to predict what certain things will reveal in the experiment. And we have to do this in the context of making skilled decisions about the best way to run the experiment. In those, we use in making use of —to gather — a wide range of scientific and practical information using the strategies of skilled decision making to design such experiments well.

Do we always have to conduct experiments like this? We have experimented described above in order to assess the validity of scientific judgments about what is causing the death of the game birds? Certainly if we do not know why, or have relevant data about why, the birds died, such an experiment would be called for. But science is a social and public enterprise. In order to find out whether certain environmental causes certain diseases, we may not have to conduct every experiment ourselves. The experiments may already have been carried out and to establish conclusively the existence of a cause/reaction relationship. Then all we have to find out is that the experimental results have already been obtained by experts also. Of course, even if we are relying on information from another source, we should make skillful judgments about the validity of the source. But we may, indeed, find that the source is impeccable and that the experiments have been repeated and the results confirmed many times. Then it may be astute to do this all over again. Likewise, we may identify the reasons the food and find out, by reading a relevant book or article, in asking someone who knows about such conditions, that birds have already been shown that establishes that these rumors are poisonous to these same hens.

All of this is proper science just as much as laboratory work is. In fact, some of the greatest scientific discoveries of the century have involved creatively putting together data derived from the work of others in generating new ideas that contrast us with powerful and well-supported explanatory hypotheses that are not breakthroughs in science. Fundamentally, the work that Dr. Richard Feynman did in developing a relativistic model for the structure of the PDA's, work for which he was awarded a Nobel Prize, involved drawing on the research of others, especially the atomistic theory work of Enrico Fermi and the work of Linus Pauling, and was not derived from new experimentation of their own.

Applying Science to Solve Problems

Is this what science is all about, and does this portrayal of scientific thinking capture the essence of this great enterprise? Many who choose otherwise say that it is. In science, we are told, we hypothesize, collect data, analyze the data, and summarize our results. But this is too narrow a view of science to capture its richness and to explain its achievements. If we think for a moment about many of the great scientific advances of the century like the development of neural signals of vaccination against diseases, of computers, and of the space shuttle we realize that science, and scientific thinking, is a broader enterprise than just developing an understanding of how the world works to work.

Without diminishing the importance of this kind of thinking, let's try the example of trying to minimize what is killing the game hens in a broader context. This product is one to which, obviously, the hen farmers are very things that not only pose their own from dying—indeed, that will keep their hens healthy and flourishing. Their perception of this as a problem is the overall context in which the experiment described above becomes relevant. Information about what is killing the hens is due, once confirmed by the experiment, can then be used to make judgments about how to solve the problem of the dying hens. In fact, overall, asset
know that the answers to such questions are often not at all simple or easy to get. A person who raises such questions and is motivated to seek answers to them using the best scientific techniques is a person who has the kind of scientific frame of mind that has guided, and at times, inspired the great discoveries in science. These attitudes and commitments have always been as much a part of scientific thinking as the actual procedures used by scientifically minded people to gain understanding and solve problems using what we know in science. Both a scientific frame of mind and sound scientific practice are essential to expanding the body of scientific knowledge.

Science Literacy and Scientific Thinking

Do only professional scientists use scientific thinking? Suppose that when we inquire about how we might deal with the poisonous worms we find out that there is a well-known and totally effective low-cost remedy for such poisoning that completely counteracts the effects of these worms. Then we may find that our problem can be solved quite simply. Is the thinking we are doing still respectable scientific thinking? We believe that even such apparently "lowest-common-denominator" thinking is still scientific if practiced with the same standards as any other type of thinking we do in science. The scientifically literate person—a person who has a basic understanding of the concepts and ideas of modern science and knows how to get scientific information, how to verify that it is accurate and reliable, and then how to use it to solve problems well—can be engaging in quite respectable scientific problem solving even though he or she may not have and practice the technical and experimental skills of the research scientist.

Likewise, it doesn't take a research chemist to recognize that the laundry detergent "experiments" featured in the well-known "ring-around-the-collar" television commercial are suspect. Two dirty shirts with heavily soiled collars are placed in separate washing machines with the sponsor's product in one and some other brand in the other. After a little time lapse, the dirt around the collar of the shirt that seemed to be the one washed in the sponsor's detergent was gone, while the collar of the shirt washed in the other brand looked the same as it had looked before—with a "ring-around-the-collar." When a person resists such an advertisement because they realize that we don't know that variables like the water temperature, amount of detergent used, etc. have been controlled, this person is using good scientific thinking to avoid making an ill-founded inference, even though this person may not be a research scientist.

Teaching Science is Teaching Basic Scientific Knowledge and Scientific Thinking to All Students

It is scientific thinking, in this broad sense, that we believe science education ought to aim at. Helping students respect and do well and not just limit itself to basic scientific information and the more narrow skills of laboratory and experimental procedure. Hence, the lessons we include speak to how we can do our best to infuse instruction in critical and creative thinking into science instruction in secondary school to maximize our impact in teaching all students to be careful, skilled, scientific thinkers in ways that they can use in their lives, even if they are not going to become laboratory technicians or research scientists.
Chapter 15: Handling Children's Questions

by Wynne Harlen

Notwithstanding the value to children's learning of encouraging their questions, many teachers feel that to do this would only add to their problems. Don’t children already ask enough questions and ones which their teachers find difficult to answer? Indeed it is not all that rare for teachers to adopt classroom materials and strategies which either keep children so busy in routines that they have little time to think and query or else themselves do all the talking and discourage any input from children which is not a response to a teacher’s question. So if the ideas suggested in the last chapter for encouraging children’s questions are to be taken at all seriously, being able to handle the questions which children raise has a high priority.

Fortunately handling questions is a skill which can readily be developed. It requires thought about the kind of question being asked, about the likely motive for asking it and knowledge of how to turn a question into one which can be a useful starting point for investigation. The word ‘handle’, rather than ‘answer’ is used deliberately here. One of the first things to realise - perhaps with some relief - is that is often better not to answer children’s questions directly (even if the teacher does know the answer). But it depends on the kind of question which is asked and so we start by identifying important differences.

Questions children ask

Most questions children ask in the context of science activities fall into one of five categories which have been chosen because they group together questions requiring different kinds of responses.

(i) Comments expressed as questions

These are questions which children ask when they are intrigued or excited. The questions don’t really need to be answered but there has to be some response which acknowledges the stimulus which gave rise to the question. For example, here is how an infant’s teacher handled a question from a six year old when she and a group of children were examining a birds’ nest:

Child: How do they weave it?
Teacher: They’re very clever...
Child: Birds are very clever with their beaks
Child: Nobody would ever think they were because they’re so small
Teacher: Yes, it’s wonderful isn’t it? If we turn this right round and let you have a look at this side........

The child’s question was used to maintain the close observation of the nest and a sense of wonder. She might have replied “Look carefully and see if you can tell how it is done?” but perhaps she judged that this was too early a stage in the exploration for focusing on one aspect, but her response leaves open the possibility of
returning to the subject in this vein if the children’s interest is still there. Another way of putting this is that she judged the question to be a way of expressing wonder rather than a genuine query. The child might just as easily have said “look at how it is woven!”

(ii) Philosophical questions
This is another category of questions to which the response has to be of the ‘yes, isn’t it interesting/intriguing’ kind, sharing the wondering behind the question. ‘Why do we have birds and all different things like that?’ is such a question. Taken at face value the only answer is to say that there is no answer. However, not all children’s questions are to be taken at face value; the motive for asking has also to be taken into account (see p 00). Neither should we read too much into the exact words children use. They often phrase questions as ‘why’ questions, making them sound philosophical when the answer they are wanting is much more related to ‘what makes it happen’ rather than ‘why does it happen’. When children’s question seem philosophical the initial step is to ask them to explain their question. It may well then turn into a question in a different category, but if not it should be treated as an interesting question but one to which no-one can give a definite answer.

(iii) Requests for simple facts
These are questions which satisfy the urge to name, to know, to identify. The children looking at the bird’s nest asked “Where did it come from?” “What kind of stuff is this that it’s made of?” “How long do the eggs take to hatch?” These are questions to which there are simple factual answers which may help the children to give a context to their experience and their ideas about the lives of birds. The teacher may know the answers and if so there is no point in withholding them. In the case of the birds’ nest she knew where it had come from and helped the children identify the ‘stuff’ as hair. But for the length of hatching she did not have the knowledge and the conversation ran on as follows:

Teacher: Well, you’ve asked me a question that I can’t answer - how many days it would take - but there’s a way that you could find out, do you know how?
Child: Watch it.....
Child: A bird watcher....
Child: A book
Teacher: Yes, this is something you can look up in a book and when you’ve found out........
Child: (who had rushed to pick up the book by the display of the nest).......I’ve got one here, somewhere.
Child......here, here’s a page about them
Teacher: There we are........

The group was engrossed in the stages of development of a chick inside an egg for some time. The question was answered and more was learned besides. Had the book not been so readily available the teacher could have suggested that either she or the children could look for the information and report back another day.
Requests for names of things fall into this category, as do definitions which arise in questions such as ‘Is coal a kind of rock?’ Whilst names can be supplied if they are known, undue attention should not be given to them. Often children simply want to know that things do have a name and, knowing this, they are satisfied. If work requires something to be named and no-one knows the proper name at that moment then children can be invited to make up a name to use. ‘Shiny cracked rock’, ‘long thin stem with umbrella’, ‘speedy short brown minibeast’ will actually be more useful in talking about things observed in the field than their scientific or common names. Later the ‘real’ names can be gradually substituted.

Some requests for simple facts cannot be answered. Young children often have a view of their teacher as knowing everything and it is necessary to help them to realise that this is not the case. When the children asked “Where are the birds now, the ones who built the nest?” they were expecting a simple question to have a simple answer. In this case the teacher judged that the kind of answer they wanted was “They’ve probably made their home in another shed, but I really don’t know for sure” rather than an account of all the possibilities, including migration and whether or not birds tend to stay in the same neighbourhood. A straight “I don’t know” answer helps children to realise the kinds of questions that cannot have answers as well as that their teacher is a human and not a super-human being.

(iv) Questions requiring complex answers
Apart from the brief requests for facts, most questions children ask can be answered at a variety of levels of complexity. Take “why is the sky blue?” for example. There are many level of ‘explanation’ from those based on the scattering of light of different wavelength to those relating to the absence of clouds. Questions such as ‘why is soil brown?’ “why do some birds build nests in trees and others on the ground?” “how to aeroplanes stay up in the air?” fall in this category.

They seem the most difficult for teachers to answer but they are in fact the most useful questions for leading to investigations. Their apparent difficulty lies in the fact that many teachers do not know the answers and those who do will realise that children could not understand them. There is no need to be concerned, whichever group you fall into, because the worst thing to do in either case is to attempt to answer these questions!

It is sometimes more difficult for the teacher who does know the scientific explanation to resist the temptation to give it than to persuade the teacher who does not know not to feel guilty about not being able to answer. Giving complex answers to children who cannot understand them is underlining for them that science is a subject of facts to memorise that you don’t expect to understand. If their questions are repeatedly met by answers which they do not understand the children will cease to ask questions. This would be damaging, for these questions particularly drive their learning.

So what can be done instead of answering them? A good answer is given by Sheila Jelly in the following words:
"The teaching skill involved is the ability to ‘turn’ the questions. Consider, for example, a situation in which children are exploring the properties of fabrics. They have dropped water on different types and become fascinated by the fact that water stays ‘like a little ball’ on felt. They tilt the felt, rolling the ball around, and someone asks ‘Why is it like a ball?’ How might the question be turned by applying the ‘doing more to understand’ approach? We need to analyse the situation quickly and use what I call a ‘variables scan’. The explanation must relate to something ‘going on’ between the water and the felt surface so causing the ball. That being so, ideas for children’s activities will come if we consider ways in which the situation could be varied to better understand the making of the ball. We could explore surfaces, keeping the drop the same, and explore drops, keeping the surface the same. These thoughts can prompt others that bring ideas nearer to what children might do."

(Sheila Jelly, 1985, p55)

The result of the ‘variables scan’ is to produce a number of possible investigable questions such as ‘Which fabrics are good ball-makers?’ ‘What happens if we use other fluids, or put something into the water?’ Exploring questions of these kinds leads to evidence which can be interpreted to test hypotheses concerning what it is about felt that makes it a good ball-maker (and can we use this idea to make it into a poor ball-maker?) and what extent it is something about water which makes it form balls (and how we can change this). These activities lead towards an explanation of the original question and can be pursued as far as the extent of the children’s interest and understanding. It is not difficult to see that there is far greater educational potential in following up the question in this way than in attempting to give an explanation (which probably has to be in terms of a misleading ‘skin’ round the surface of the drop).

‘Turning’ questions into investigable ones is an important skill since it enables teachers to treat difficult questions seriously but without providing answers beyond children’s understanding. It also indicates to children that they can go a long way to finding answers through their own investigation, thus underlining the implicit messages about the nature of scientific activity and their ability to answer questions by ‘asking the objects’ (see Chapter 14, p00).

(v) Questions which can lead to investigation by children

Teachers looking for opportunities for children to explore and investigate will find these are the easiest questions to deal with. The main problems

a) recognising such questions for what they are
b) resisting the urge to give the answer because it may seem so evident (to the teacher but not the child)
c) storing them, when they seem to come at the wrong time.

a) It is not often that a child expresses a question in an already investigable form; there is usually a degree of ‘turning’ to do and the ‘variables scan’ is a useful idea to keep in mind. The example of the snails’ shells (p00) is a case in point. Here the questions ‘Why do snails have four rings on their shell?’ was quite easily turned into ‘Do snails have the same number of rings on their shells?’ A slightly different approach is to turn a question
from a ‘why’ question into a ‘what would happen if’ question. For instance:
‘Why do you need to stretch the skin tight on a drum?’ can become ‘What would happen if the skin is not tight?’

Not only is this more encouraging for the child than a straight return of the question: ‘Well, what do you think?’ but it directs the child towards finding out more than the answer to the original question - in this case probably the relationship between the pitch of the sound and the tautness of the drum skin.

b) ‘What are these?’ (the eyes of sprouting potatoes)
‘Where did these come from?’ (winged fruits of sycamore trees)
‘How can I stop my tower falling over?’ (tower built from rolled newspaper with no diagonal struts).

These are questions which the teacher could readily answer, but in most cases to do so would deprive the children of good opportunities to investigate and learn much more than the simple answer. Certainly, there can be occasions when it is best to give the short answer, but in general the urge to answer is best resisted. Instead it is best to discuss how the answer can be found.

c) Questions which can be profitably investigated by children will come up at various times, often times which are inconvenient for embarking on investigations. Although they can’t be taken up at that moment the question should be discussed enough to turn them into investigations and then, depending on the age of the children, picked up some time later. Some kind of note has to be made and this can usefully be kept publicly, a list of ‘things to investigate’ on the classroom wall, or just kept privately by the teacher. For younger children the time delay in taking up the investigations has to be kept short - a matter of days - but the investigations are also short and so can be fitted into a programme more easily. Older children can retain interest over a longer period - a week or two - during which the required time and materials can be built into the planned programme.

The five categories of questions and ways of handling them are summarised in figure 15.1.

Flow diagram for handling questions

Children’s motives for questioning
So far we have treated children’s questions as if they all stem from curiosity and a desire to understand. These are, of course, powerful motives for questioning and are the basis of the reasons given for encouraging questions (p00). But there are other motives which overlay the distinctions between categories proposed above. Children also ask questions to demand attention; they are less interested in the answer than in being the focal point of the class for a few minutes. One little girl made a habit of putting her hand up and then asking a
question in such a whispering voice that the whole class had to freeze in order for her to be heard. The teacher did not want to discourage her questions by not allowing her to speak or to be heard, but found the effort disrupted the flow of discussion. Other children use questions to seek gradually more and more clues to what they are expected to do that they end up being with far more help than other children. When such subterfuges work the children use them more frequently and they spread to others. The way to avoid this is not to let them work; to recognise them for what they are and to make it explicit to the child that the teacher realises what is happening.

Recognising that the motive for a question may not be purely a desire to know, the teacher has to modify the ways of handling suggested above. At the same time the situations can be used to reinforce the preference for questions which are investigable, giving praise and attention to such questions whilst expecting children to do more fact-finding for themselves.