DOCUMENT RESUME

ED 445 917 SE 064 125

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TITLE	Teaching and Learning Science and Mathematics in Diverse Classrooms: A Resource for Collaboration and Discussion.
INSTITUTION	TERC, Cambridge, MA. Cheche Konnen Center.
SPONS AGENCY	Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE	2000-00-00
NOTE	177p.
CONTRACT	RJ96006401
PUB TYPE	Guides - Classroom - Teacher (052) -- Guides - Non-Classroom (055)
EDRS PRICE	MF01/PC08 Plus Postage.
DESCRIPTORS	*Cultural Influences; *Discourse Analysis; *Diversity (Student); *Educational Resources; Elementary Secondary Education; Mathematical Linguistics; Mathematics Education; Science Education

ABSTRACT

The articles in this collection offer rich and provocative views, backed by research and intensive classroom experience, of science and mathematics and teaching and learning. In particular, they explore some combination of the following: (1) science and mathematics as discourses; (2) students' home- and culturally-based ways of knowing, talking, and valuing; (3) classroom talk and activity; (4) views of learning as inquiry; and (5) teacher research. Articles are arranged in three sections entitled "Linguistically and Culturally Diverse Classrooms", "Learning as Inquiry", and "Teaching as Inquiry". Four of the articles represent research in linguistically and culturally diverse classrooms. The next three articles describe different aspects of inquiry-based learning, and the last three explore learning to consider new roles for the teacher in the classroom. Not all of the articles address linguistically and culturally diverse classrooms. Several articles address issues that are important for all learners: for example, the importance of allowing children to work through their confusion, allowing children's different ideas to come into contact, and teachers coming to understand the rich connections between children's experience, and scientific and mathematical ideas and practices. (ASK)

Teaching and Learning Science and Mathematics in Diverse Classrooms:

A Resource for Collaboration and Discussion

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This publication is based on work supported by the Office of Educational Research and Improvement (OERI), U.S. Department of Education, under Contract Number RJ96006401. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of OERI, the U.S. Department of Education, or any other agency of the U.S. Government.

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A Resource for Collaboration and Discussion

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Introduction

A class of seventh and eighth grade students design an investigation of their belief that the water from the third floor drinking fountain at their school is better than that from other fountains at the school. To test their belief they conduct a blind taste test of the water and find that students actually prefer water from the first floor. To account for the differences, they measure the water temperature and analyze the water for acidity, alkalinity and bacterial content. These children are Haitian students doing science in a bilingual classroom, children who came to school with a diversity of experiences and literacies, some of which differed from those valued in school and in school science. Yet in conducting this investigation, the children were given the opportunity to interweave multiple literacies — in science, in mathematics and in language arts — as they acquired new ways to communicate in both their first and second languages.

In 1983 the National Science Foundation (NSF) set the ambitious goal of providing "high standards of excellence for all students — wherever they live, whatever their race, gender, or economic status, whatever their immigration status or whatever language is spoken at home by their parents, and whatever their career goals."[1] During the period since the report's publication, reform movements in science and mathematics have flourished, with major initiatives undertaken by the NSF, the American Association for the Advancement of Science, the National Council of Teachers of Mathematics, and the National Research Council of the National Academy of Sciences. However, the science and mathematics reform movements have yet to address the complexities of implementing educational reform for students in culturally and linguistically diverse classrooms.[2] Many of these students receive *no* science instruction at all; for those who do, science is often restricted to a lesson in English language structures and vocabulary. Moreover, most bilingual, ESL and classroom teachers, especially at the elementary grades, have limited backgrounds in science or mathematics. Science and mathematics teachers, for their part, have little or no education in issues of cultural and linguistic diversity in relation to science and mathematics teaching and learning.

Despite this general lack of focus, several research groups have explicitly explored learning in science and mathematics in culturally and linguistically diverse classrooms, as well as new models of professional development and curriculum design (see Appendix A). In addition, other researchers, while not focused on these students, have contributed important insights and perspectives on science and mathematics teaching and learning for all students (see Appendix B).

This resource packet is, we believe, unique in presenting these bodies of work together in one place. We hope that the packet will be used in a variety of ways among different groups. For example, it could serve as a beginning resource that provokes thought, stimulates discussion and generates questions for the teachers, staff developers, principals, and education students who read it. It could be used as a teacher examines his/her practice. It could serve as a basis for discussion among teachers as a shared beginning for exploring issues of student learning and classroom practice. Whatever their use, we hope that the perspectives presented in the packet will inform educators' thinking about teaching science and mathematics to linguistically and culturally diverse student populations.

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1 National Science Foundation. (1983). Educating Americans for the Twenty-First Century. National Science Foundation, Washington, DC.

2 In using the phrase "linguistically and culturally diverse," we refer to classrooms in which many students' home language is not standard English.

Introduction to the articles

The articles in this collection were chosen because they offer rich and provocative views — backed by research and intensive classroom experience — of science and mathematics and of teaching and learning. In particular, they explore some combination of the following: science and mathematics as discourses;[3] students' home- and culturally-based ways of knowing, talking, and valuing; classroom talk and activity; views of learning as inquiry; and teacher research.

The articles are arranged in three sections, entitled i) Linguistically and culturally diverse classrooms, ii) Learning as inquiry, and iii) Teaching as inquiry. Two of the articles (Rosebery et al. 1992; Ballenger 1997) were published by staff of the Chèche Konnen Center. These two, together with the next two (Brenner 1996; Garcia 1991), represent research in linguistically and culturally diverse classrooms. The next three articles describe different aspects of inquiry-based learning (Center for Science Education 1997; Duckworth 1987; Nemirovsky 1993), and the last three explore learning to consider new roles for the teacher in the classroom (Ball 1991; Gallas 1995). Not all the articles deal with linguistically and culturally diverse classrooms; several articles address issues that are important for all learners — for example, the importance of allowing children to work through their confusion, of allowing children's different ideas to come into contact, and of teachers coming to understand the rich connections between children's experience and scientific and mathematical ideas and practices.

i) Linguistically and culturally diverse classrooms

All the articles in this section focus on teaching and learning in linguistically and culturally diverse classrooms. The first two case studies (Rosebery et al. and Ballenger) focus on teaching and learning science; the third (Brenner) is a synthesis of research in mathematics classrooms; and the fourth (Garcia) is a general review of effective instructional practices. All share to some extent the views that the disciplines of science and mathematics are, first and foremost, social and cultural practices, that culturally and linguistically diverse classrooms in which students excel are classrooms where instruction builds on home language and culture, and that talk among students is an important aspect of classroom practice.

3 "Discourses" here is used to identify science and mathematics as historically and culturally constituted ways of conceptualizing, evaluating and representing the world, characterized by particular ways of knowing, talking and valuing.

In the introduction to their article, Rosebery et al. use the term "scientific sense-making" to underscore their view that science is a particular way of conceptualizing, evaluating and representing the world. Learning science means developing command over particular bodies of scientific knowledge and practices for negotiating among alternative interpretations, making sense out of often contradictory observations and measurements, and making sense through scientific argument.

In the second article Ballenger points out that, in general, school is a site of many discourses. Students from linguistically and culturally diverse groups, among others, arrive at school familiar with family and neighborhood linguistic and social practices. However, the linguistic and social practices of school, and of science and mathematics more particularly, are frequently unfamiliar to many students. Ballenger suggests that these students will enter into and engage more successfully with the discourse of science if their home-based ways of using language and of making sense are regarded as acceptable forms of participation in the science classroom.

Brenner presents a view of mathematics as a socially and historically constituted discourse. Building on the notion that all learning takes place within a social context, she emphasizes that communication between the world of mathematics and the particular cultural and social worlds of students from linguistically and culturally diverse backgrounds is a way to begin to enculturate students into the discipline of mathematics. This approach is in accord with the mathematics reform movement, which has emphasized changing norms of classroom discourse. Likewise, Garcia's survey of recent research on linguistically and culturally diverse classrooms in which students have been particularly successful emphasizes that instructional strategies that build on students' home language and culture serve these students particularly well.

ii) Learning as inquiry

A focus on genuine inquiry underlies all Chèche Konnen work with teachers and students. Genuine inquiry tends to foster scientific and mathematical practices in the classroom that resemble more closely those practices in which scientists and mathematicians engage than do traditional school science and mathematics. In our research (e.g., Rosebery et al. 1992, Ballenger 1997), we have found that encouraging genuine inquiry in the classroom has been an important principle in allowing students in linguistically and culturally diverse classrooms (and indeed in all classrooms) to flourish as learners of science and mathematics.

The articles in this section further describe aspects of inquiry-based learning from several points of view. The Center for Science Education chapter provides an overview of "inquiry-based teaching," which the authors describe as modelled on "the scientists' method of discovery." The article emphasizes, among other things, guiding students in active and extended scientific inquiry, providing opportunities for scientific discussion and debate among students, and sharing responsibility for their learning with students.

Duckworth and Nemirovsky emphasize particular aspects of inquiry-based learning that are important in their work. Duckworth, for example, writes about the importance of exploring ideas, particularly "wrong" ones, and of allowing time for exploring confusions. Nemirovsky describes the importance of preserving and enriching a childlike perspective on nature, thereby affording learners the opportunity to consider everyday or familiar phenomena with a fresh eye.

iii) Teaching as inquiry

Effective professional development of teachers, we believe, engages teachers in two interwoven forms of inquiry: inquiry in science and mathematics and inquiry into their students' learning and discourse. In the Chèche Konnen Center, teachers are researchers in their own classrooms, exploring how their own learning and teaching practices, their students' discourse and learning, and the discourses of science and mathematics relate to one another. By viewing teaching as inquiry (or themselves as researchers), teachers can consider playing new roles in their classrooms.

Both Gallas and Ball present narratives from their own classrooms exploring the following to different degrees:

1) Science and mathematics as bodies of knowledge and as particular ways of conceptualizing, representing and evaluating the world (views of science and mathematics common to other articles in this packet)
2) The concrete particulars of students' ways of talking and knowing (rather than generalities about groups in the abstract)
3) The deep connections between their students' ways of talking and knowing and those of science and mathematics.

Using the Articles

We hope that this collection will be a useful resource to any reader who seeks a brief introduction to recent research in science and mathematics teaching and learning in linguistically and culturally diverse classrooms. To this end, this resource packet is designed to be read alone. However, we believe that discussing the articles with others will open up new perspectives about science and mathematics teaching and learning and provide a shared beginning for exploring different points of view. For this reason, we recommend that interested readers form a discussion group to meet regularly; depending on their needs and preferences, they may meet weekly, biweekly, monthly, or intensively in the summer. Teacher research groups can take different forms, with leadership coming from teachers, researchers, staff developers, or some combination of each.

The group might begin by choosing at least one article from each of the three sections (for example, Rosebery et al., Duckworth, and Ball). After reading each article, we suggest that members first consider what the author is attempting to communicate so as to build a shared sense of the reading:

What are her purposes or questions?

What case is she making?

What does she offer as a rationale and as evidence for her ideas?

Then, on closer reading, we encourage members to consider the following:

What is your response to what the author is saying and does it connect in any way with issues, concerns, questions in your own teaching?

What surprises you?

What do you agree with?

What do you find unconvincing or want to argue against?

What evidence do you have in support of your claim, or what evidence would you need or could you develop?

What new questions do you have? In what ways can you continue exploring your questions and ideas?

We have found that as a group meets together over time to discuss articles like these and as members grapple with their diverse perspectives and experiences, shared ways of talking about science and mathematics and about teaching and learning emerge. In addition to the general questions above, the more specific questions that follow should be helpful in facilitating a deeper examination of the issues raised by each article. The questions are suggested with a number of purposes in mind: to develop some shared view of the author's intent; to put the author's point of view into contact with other points of view within the group; and to begin to put the reading into contact with teachers' thinking about their own practice.

In the Chèche Konnen seminar,[4] for example, a discussion of the Gallas readings helped shape classroom talk for a number of teachers. Initiating "science talks" opened up space in their classrooms for their students' thinking and arguments about scientific phenomena to emerge. Reading the Ballenger article led to a discussion of the connections that can be made between "everyday" and "scientific" ways of talking. We also used a discussion of the Ball article to explore what a discourse of mathematics might mean in the classroom and how it is shaped by both teacher and students.

We encourage members of the group to use examples from their own practice in their responses to the readings. Over the longer term, teachers may want to collect data to help them investigate their practice in relation to the issues, ideas, and dilemmas raised by the readings. Teachers might tape record or videotape conversations in their classrooms or take classroom notes to share with the group. (See Gallas, 1995, for more detail on how she documented her students' discourse.)

4 See the Chèche Konnen Web site (http://www.projects.terc.edu/cheche konnen) for more information about teacher research both at the Center and more generally.

In the Chèche Konnen seminar, teachers regularly video and audiotape student conversations in their classrooms. They then transcribe segments that interest them, and discuss these with their colleagues in the seminar.[5] By "stopping time"[6] in this way, they are able to examine closely students' ideas and discourse. They have found this helpful in tracing students' understandings, seeing how students' everyday experiences and ways of talking connect with science and mathematics, how students' approaches to science and mathematics frequently open up their own understandings of the disciplines, and how they themselves give shape to students' learning and participation. In addition, teachers often see connections and similarities between their own and their students' learning in science and mathematics.

5 For a video portrayal of teachers' work with videotapes and transcripts, see B. Warren and M. Bodwell. (1997). "Why do big, heavy boats float?" Teacher inquiry into student learning. Portsmouth, NH: Heinemann. The Chèche Konnen Web site has information on obtaining this and related resources.

6 Phillips, A. (1993). Raising the teacher's voice: The ironic role of silence. In Children's voices, teacher's stories: Papers from the Brookline Teacher Researcher Seminar, pp.1-9, Newton MA: The Literacies Institute, Education Development Center.

The Chèche Konnen Center

The mission of the Chèche Konnen Center is to improve science and mathematics education for elementary and middle school students whose first language is not English. The work of the center is based on approximately ten years of classroom-based research on science teaching and learning in Haitian Creole and Spanish bilingual classrooms, conducted in collaboration with teachers and students in the Boston and Cambridge, MA public schools. Center staff work with school districts to tailor district plans for professional development in science and mathematics for teachers in linguistically and culturally diverse classrooms. The center's approach to teacher professional development integrates teachers' inquiry in science and mathematics with inquiry into their students' learning and discourse.

Working in collaboration with the center, teachers come together biweekly during the school year and for one week in the summer in ongoing professional development seminars. In the seminars they explore their own questions about scientific phenomena and about mathematics, and study the connections among their own, their students', and scientists' and mathematicians' ways of making sense of the world. The teachers conduct their own inquiries in science and in mathematics which, in the seminars, are interwoven with inquiry into the ways their children make sense of and "talk" science and mathematics. In the classroom, when the teachers engage their students in doing science and doing mathematics, they encourage their students to pose questions, build theories, examine assumptions, develop evidence, argue alternative interpretations, and so forth. As students do science and mathematics, they also have multiple and varied opportunities to use language — both first and second — as a resource for making sense of scientific or mathematical ideas.

Articles included in this resource

Ball, D.L. (1991). What's all this talk about discourse? *The Arithmetic Teacher,* November 1991, 44-47.

Ballenger, C. (1997). Social identities, moral narratives, scientific argumentation: Science talk in a bilingual classroom. *Language and Education 11(1),* 1-14.

Brenner, M.E. (1994). A communication framework for mathematics: Exemplary instruction for culturally and linguistically diverse students. In B. McLeod (Ed.), *Language and learning: Educating linguistically diverse students,* (pp. 233-267). Albany, NY: State University of New York Press.

Center for Science Education. (1997). A vision of effective science education. In J.S. Dietz. (Ed.), *Foundations: The challenge and promise of K-8 science education reform,* (pp. 7-16). Arlington, VA: National Science Foundation.

Duckworth, E. (1987). Learning with breadth and depth. In *The having of wonderful ideas,* (pp. 70-82). New York: Teachers College Press.

Gallas, K. (1995). What is science? In *Talking their way into science,* (pp. 7-16). New York: Teachers College Press.

Gallas, K. (1995). Science talks: An overview. In *Talking their way into science,* (pp. 17-31). New York: Teachers College Press.

Garcia, E. (1991). Education of linguistically and culturally diverse students: Effective instructional practices. *Educational practice report #1.* Santa Cruz, CA: University of California, National Center for Research on Cultural Diversity and Second Language Learning.

Nemirovsky, R. (1993). Don't tell me how things are, tell me how you see them. In R. Ruopp, S. Gal, B. Drayton, & M. Pfister (Eds.), *LabNet: Towards a community of practice,* (pp. 269-280). Hillsdale, NJ: Erlbaum.

Rosebery, A.S., Warren, B., Conant, F.R., & Hudicourt-Barnes, J. (1992). Chèche Konnen: Scientific sense-making in bilingual education. *Hands On! 15(1),* 1,16-19.

Appendix A

Selected research on science and mathematics teaching and learning in linguistically and culturally diverse classrooms

Mathematics

Khisty, L.L. (1995). Making inequality: Issues of language and meanings in mathematics teaching with Hispanic students. In W.G. Secada, E. Fennema, & L.B. Adajian (Eds.), *New directions for equity in mathematics education,* (pp. 279-297). New York: Cambridge University Press.

Khisty, L.L. (1997). Making mathematics accessible to Latino students: Re-thinking instructional practice. In J. Trentacosta & M.J. Kenney (Eds.), *1997 yearbook: Multicultural and gender equity in the mathematics classroom: The gift of diversity,* (pp. 92-101). Reston VA: National Council of Teachers of Mathematics.

Khisty, L.L., McLeod, D., & Bertilson, K. (1990). Speaking mathematically in bilingual classrooms: An exploratory study of teacher discourse. *Proceedings of the fourteenth international conference for the psychology of mathematics educator, vol. 3,* 105-112. Mexico City: CONACYT.

Moschkovich, J.N. (1996). Moving up and getting steeper: Negotiating shared descriptions of linear graphs. *The Journal of the Learning Sciences, 5(3),* 239-277.

Moschkovich, J.N. (1999). Learning mathematics in two languages: Moving from obstacles to resources. To appear in W. Secada (Ed.), *Changing faces of mathematics (vol. 1): Perspectives on multiculturalism and gender equity.* Reston, VA: NCTM.

Secada, W.G., Fennema, E., & Adajian, L.B. (Eds.). (1995). *New directions for equity in mathematics education.* New York: Cambridge University Press. [also available in Spanish: Secada, W.G., Fennema, E., & Adajian, L.B. (Comps). (1997). *Equidad y enseñanza de las matemáticas: Nueva tendencias.* Madrid: Ediciones Morata.]

Science

Conant, F.R. (1996). Drums in the science lab. *Hands On! 19(1)*. Cambridge, MA: TERC.

Gallard, A.J. & Tippins, D.J. (1994). Language diversity and science learning: The need for a critical system of meaning. In B. McLeod (Ed.) *Language and learning: Educating linguistically diverse students,* (pp. 269-288). Albany, NY: State University of New York Press.

Rosebery, A., Warren, B., & Conant, F. (1991). Chèche Konnen: Collaborative scientific inquiry in language minority classrooms. *Cooperative Learning 11,* 28-29.

Rosebery, A., Warren, B., & Conant, F.R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *The Journal of the Learning Sciences 2,* 61-94.

Warren, B., Puttick, G.M., Conant, F.R., & Rosebery, A.S. (1992). Sense-making practices in science. *Hands On! 15(2)*. Cambridge, MA: TERC.

Warren, B., & Rosebery, A. (1992). Science education as a sense-making practice: Implications for assessment. *Proceedings of the second national research symposium on limited english proficiency student issues: Focus on evaluation and measurement, vol. 2*. Washington, D.C.: U.S. Department of Education.

Warren, B., & Rosebery, A. (1995). Equity in the future tense: Redefining relationships among teachers, students and science in linguistic minority classrooms. In W. Secada, E. Fennema, & L. Adajian (Eds.), *New directions for equity in mathematics education,* (pp. 289-328). New York: Cambridge University Press.

Warren, B., & Rosebery, A. (1996). "This question is just too, too easy!" Students' perspectives on accountability in science. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education,* (pp. 97-126). Mahwah, NJ: Erlbaum.

Warren, B., Rosebery, A.S., & Conant, F.R. (1994). Discourse and social practice: Learning science in bilingual classrooms. In D. Spener (Ed.), *Adult literacy in the United States*. Washington DC: Center for Applied Linguistics and Delta Systems.

Appendix B

Selected research on science and mathematics teaching and learning

Mathematics

Ball, D. (1990). *With an eye on the mathematical horizon: Dilemmas of teaching elementary school mathematics.* (Craft Paper 90-3). East Lansing, MI: Michigan State University, National Center for Research on Teacher Learning.

Ball, D. (1999). What do students know? Facing challenges of distance, context, and desire in trying to hear children. In B.J. Biddle, T.L. Good, & I.F. Goodson (Eds.), *International handbook of teachers and teaching, vol. 2,* (pp. 769-817). Dordrecht, Netherlands: Kluwer Academic.

Chazan, D., & Ball, D. L. (1995). *Beyond exhortations not to tell: What is the teacher's role in discussion-intensive mathematics classes?* (Craft Paper 95-2). East Lansing, MI: Michigan State University, National Center for Research on Teacher Learning.

Cobb, P. (1995). Cultural tools and mathematical learning: A case study. *Journal for Research in Mathematics Education 26,* 362-385.

Cobb, P., Wood, T., and Yackel, E. (1993). Discourse, mathematical thinking, and classroom practice. In N. Minick, E. Forman, & C. Stone (Eds.), *Contexts for learning: Sociocultural dynamics in children's development,* (pp. 91-119). New York: Oxford University Press.

Collins, A., Brown, J.S., & Newman, S. (1989). Cognitive apprenticeship: Teaching the craft of reading, writing, and mathematics. In L. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser.* Hillsdale, NJ: Elrbaum.

Forman, E. A. (in press). Learning mathematics as participation in classroom practice: Implications of sociocultural theory for educational reform. In L. Steffe (Ed.), *Theories of mathematics education.* Mahwah, NJ: Erlbaum.

Godfrey, L. & O'Connor, M. C. (1995). The vertical hand span: Non-standard units, expressions and symbols in the classroom. *Journal of Mathematical Behavior 14*, 327-345.

Lampert, M. (1986). Knowing, doing and teaching multiplication. *Cognition and Instruction 3(4)*, 305-342.

Lampert, M. (1988). The teacher's role in reinventing the meaning of mathematical knowing in the classroom. In M.J. Behr, C.B. Lacampagne, & M.M. Wheeler (Eds.), *Proceedings of the tenth annual conference of the North American chapter of the International Group for the Psychology of Mathematics Education*, (pp. 433-480).

Lampert, M. (1990). When the problem is not the question and the solution is not the answer: Mathematical knowing and teaching. *American Education Research Journal 27*, 29-63.

Lehrer, R. & Schauble, L. (1999). Modeling in mathematics and science. In R. Glaser (Ed.), *Advances in instructional psychology, vol. 5.* Mahwah, NJ: Erlbaum.

Lehrer, R., Schauble, L., Carpenter, S., & Penner, D. (1999). The inter-related development of inscriptions and conceptual understanding. In P. Cobb (Ed.), *Symbolizing, communicating and mathematizing: Perspectives on discourse, tools and instructional design.* Mahwah, NJ: Erlbaum.

Monk, S., & Nemirovsky, R. (1994). The case of Dan: Construction of a functional situation through visual attributes. *Issues in Mathematics Education 4*, 139-168.

Nemirovsky, R. (1994). On ways of symbolizing: The case of Laura and velocity sign. *The Journal of Mathematical Behavior 13*, 389-422.

Nemirovsky, R. (1996). Mathematical narratives. In N. Bednarz, C. Kieran, & L. Lee (Eds.), *Approaches to algebra: Perspectives for research and teaching*, (pp. 197-223). Dordrecht, Netherlands: Kluwer Academic.

Nemirovsky, R., Tierney, C., & Wright, T. (1998). Body motion and graphing. *Cognition and Instruction 16(2).*

Pimm, D. (1987). *Speaking mathematically: Communication in mathematics classrooms.* London: Routledge.

Schoenfeld, A.H. (1992). Learning to think mathematically: Problem solving, metacognition, and sense-making in mathematics. In D. Grouws (Ed.), *Handbook for research on mathematics teaching and learning.* New York: Macmillan.

Yackel, E. & Cobb, P. (1996). Sociomathematical norms, argumentation and autonomy in mathematics. *Journal for Research in Mathematics Education 27,* 458-477.

Science

DiSchino, M., Sylvan, L., & Whitbeck, C. (1996). Teachers' perspectives on childrens' talk in science. *The Working Paper Series,* 2-96. Cambridge, MA: TERC.

Duckworth, E. (1987). *The having of wonderful ideas.* New York: Teachers College Press.

Gallas, K. (1995). *Talking their way into science.* New York: Teachers College Press.

Michaels, S. (1999). A pedagogy for multiliteracies: Interrogating the terms. In The New London Group (Ed.), *Multiliteracies: Literacy learning and the design of social futures.* Cambridge: Cambridge University Press.

Michaels, S. & Sohmer, R. (1999). Narratives and inscriptions: Cultural tools, power, and powerful sensemaking. In The New London Group (Ed.), *Multiliteracies: Literacy learning and the design of social futures.* Cambridge: Cambridge University Press.

Rosebery, A. & Puttick, G. (1998). Teacher professional development as situated sense-making: A case study in science education. *Science Education 82,* 649-677.

Rosebery, A.S., & Warren, B. (Eds.). (1995). *Sense making in science: A video series.* Portsmouth, NH: Heinemann.

Rosebery, A.S., & Warren, B. (Eds.). (1998). *Boats, balloons, and classroom video: Science teaching as inquiry.* Portsmouth, NH: Heinemann.

Warren, B. & Ogonowski, M. (1998). *From knowledge to knowing: An inquiry into teacher learning in science.* Center for the Development of Teaching, Paper Series. Newton, MA: Education Development Center, Inc.

Article 1

Chèche Konnen: Scientific Sense-Making in Bilingual Education

Article 1

ARTICLE 1: Chèche Konnen: Scientific Sense-Making in Bilingual Education

Rosebery, A.S., Warren, B., Conant, F.R., & Hudicourt-Barnes, J. (1992). Chèche Konnen: Scientific sense-making in bilingual education. *Hands On! 15(1)*, 1, 16-19.

Rosebery et al. use the term "scientific sense-making" to underscore their belief that scientific understanding is shaped by a community through scientific argument rather than by the discovery of facts; science is a particular way of conceptualizing, evaluating and representing the world. They describe how, in a 7th and 8th grade Haitian Creole bilingual classroom, students were given an opportunity to engage in scientific sensemaking as they explored water fountain preferences in their school. In exploring their own questions about the water in their school, students designed studies, collected, analyzed, and interpreted data, evaluated evidence, and built and argued theories. Not only were the students able to answer their questions but they also succeeded in involving the entire school in their investigation and in creating a public face for their intellectual work.

Questions

- Rosebery et al. describe what they call "sense-making" in a Haitian Creole bilingual classroom and make a case that the students are learning to participate in a "scientific sense-making community." What do you think they mean by "sense-making" and "scientific sense-making community"? Does anything about the students' talk and activity seem "scientific" to you? Why or why not?

- What, if anything, do you think the students learned (e.g., about water quality or about making scientific claims?)

- What concerns, if any, do you have about this kind of approach? about the role the teacher assumed?

- If you were the teacher, what other activities, if any, would you engage the students in to build on what they learned and how they were learning in science?

Cheche Konnen: Scientific Sense-Making in Bilingual Education

by Ann S. Rosebery, Beth Warren, Faith R. Conant, and Josiane Hudicourt-Barnes

What is the place of science in bilingual education? In many language minority classrooms it has no place at all. Science is just not a part of the bilingual curriculum. When science is taught, it is used simply as a context for developing English language skills. Students memorize the definition of the word "hypothesis" but never experience what it means to formulate or evaluate one. The emphasis is squarely on learning English vocabulary and grammar; science serves as one means toward that end. In short, language minority students do not have the opportunity to build scientific understandings of the world or to explore scientific ways of thinking and knowing.

In Haitian Creole, Cheche Konnen means search for knowledge. In undertaking this project, we sought to develop an alternative approach to science for bilingual educators and, by extension, for all educators. From our perspective, science should be valued not solely as a means for teaching English but as a way of knowing and thinking in its own right. In this light, language is a means for scientific sense-making.

What do we mean by scientific "sense-making"? We use this term to emphasize first our belief that scientific ideas grow out of human activity and thought; they are "constructed" rather than "discovered." As Sir Peter Medawar (1987), the Nobel Laureate, explains:

> *"Like other exploratory processes, [the scientific method] can be resolved into a dialogue between fact and fancy, the actual and the possible; between what could be true and what is in fact the case. The purpose of scientific enquiry is not to compile an inventory of factual information, nor to build up a totalitarian world picture of Natural Laws in which every event that is not compulsory is forbidden. We should think of it rather as a logically articulated structure of justifiable beliefs about a Possible World—a story which we invent and criticise and modify as we go along, so that it ends by being, as nearly as we can make it, a story about real life."*

Central to Medawar's vision is an idea of scientific practice in which creativity and construction, rather than discovery, predominate. His language suggests that science is projective rather than objective; scientists build stories about a possible world, they do not discover the truth that already exists "out there."


Photo credit: Ann S. Rosebery

A student tests the salinity of the school's water.

In addition, we use the term sense-making to underscore our belief that scientific understanding is shaped by a community through scientific argument rather than received from authority. Recent studies of scientists at work in laboratories (Knorr-Cetina & Mulkay, 1983; Latour & Woolgar, 1986) suggest that scientists construct and refine their ideas within a community of practice; they transform their observations into findings through argumentation, not simply through measurement and discovery. When asked what they think they are doing, scientists claim merely to be discovering facts. But close observation suggests that they are actually writers and readers in the business of convincing and being convinced by others. Rather than the orderly, logical, and coherent process that is described in science textbooks as *the* scientific method, actual scientific practice entails making sense out of frequently disorderly observations and negotiating among alternative interpretations.

In Cheche Konnen, what the students think—rather than what the text states or teacher thinks—is at the center of their activity. Students explore their own questions; design studies; collect, analyze, and interpret data; build and argue theories; evaluate evidence; and the like. At a conceptual level, students investigate their own questions and the beliefs or theories from which these derive; at an epistemological level, they explore relationships among truth, evidence, and belief in science. In the process they become authors of scientific ideas and arguments (Lampert, 1990).

A class of seventh and eighth grade Haitian students at the Graham and Parks Alternative Public School (K-8) in Cambridge, Massachusetts, demonstrated scientific sense-making with the Water Taste Test. The Water Taste Test was an investigation the students designed to investigate the "truth" of a belief held by most of the junior high students (mainstream and bilingual) that the water from the fountain on the third floor (where their classrooms are located) was superior to the water from the other fountains in their school. Challenged by their teacher, the students set out to determine whether they actually preferred water from the third-floor fountain or only thought they did. As a first step, they designed and then took a blind taste test of water from the first-, second-, and third-floor fountains. To their surprise, they found that two-thirds of them *chose* the water from the first-floor fountain, although they all *said* they preferred drinking from the third-floor fountain.

But the students did not believe the data. They held firmly to their belief that the first-floor fountain was the worst because "all the little kids slobber in it." (The first-floor fountain is located near the kindergarten and first-grade classrooms.) Their teacher was also suspicious of the results because she had expected no differences among the three water fountains. These suspicions motivated the class to conduct a second taste test with a larger sample drawn from the other junior high classes.

The students decided where, when, and how to run their experiment. They discussed methodological issues: how to collect the water, how to hide the identity of the sources, and, crucially, how many fountains to include. They decided to include the same three as before so they could compare results. They worried about bias in the voting process: what if some students voted more than once? Each student in the class volunteered to organize a piece of the experiment. About 40 mainstream students participated in the blind taste test. When the class analyzed their data, they found support for their earlier results: 88% of the junior high students *thought* they preferred water from the third-floor fountain, but 55% actually *chose* the water from the first floor.

Faced with this evidence, the students' suspicion turned to curiosity. *Why* was the water from the first-floor fountain preferred? *How* could they determine the source of the preference? They decided to analyze the school's water along several dimensions, among them acidity, salinity, and bacteria. They found that all the fountains had unacceptably high levels of bacteria. In fact, the first-floor fountain (the one most preferred) had the highest bacterial count! They also found that the water from the first-floor fountain was 20 degrees colder than the water from fountains on the other floors. Based on their findings, they concluded that temperature was probably a deciding factor in taste preference. They theorized that the water was naturally cooled as it sat in the city's underground pipes during the winter months (the study was conducted in February), and warmed as it flowed from the basement to the third floor.

This investigation is one of many conducted by language minority students within the context of the Cheche Konnen project. A sense-making approach represents a radically different orientation to teaching and learning than that found in traditional classrooms. Students *construct* scientific understandings through an iterative process of theory building, criticism, and refinement based on their own questions, hypotheses, and data analysis activities. Question posing, theorizing, and argumentation form the structure of students' scientific activity. Within this structure, students explore the implications of the theories they hold, examine underlying assumptions, formulate and test hypotheses, develop evidence, negotiate conflicts in belief and evidence, argue alternative interpretations, provide warrants for conclusions, and so forth. The process as a whole provides a richer, more scientifically grounded experience than the conventional focus on textbooks or laboratory demonstrations.

The emphasis on establishing communities of scientific practice reflects our belief, building on Vygotsky (1978), that robust knowledge and understandings are socially constructed through talk, activity, and interaction around meaningful problems and tools. The teacher guides and supports students as they explore problems and define questions that are of interest to them. A community of practice also provides direct cognitive and social support for the efforts of the group's individual members. Students share the responsibility for thinking and doing: they distribute their intellectual activity so that the burden of managing the whole process does not fall to any one individual. In addition, a community of practice can be a powerful context for constructing scientific meanings. In challenging one another's thoughts and beliefs, students must be explicit about their meanings; they must negotiate conflicts in belief or evidence; and they must share and synthesize their knowledge to achieve understanding (Brown & Palincsar, 1989; Inagaki & Hatano, 1983).

What do students learn from participating in a scientific sense-making community? To explore this question, we interviewed students individually before and after the Water Taste Test investigation, first in September, then in the following June. We examined how their knowledge and reasoning changed. In the interviews, which were conducted in Haitian Creole, the students were asked to think aloud about two open-ended real world problems: one focused on pollution in the Boston Harbor; the other on a sudden illness in an elementary school. Our analysis centered on changes in students' conceptual knowledge about aquatic ecosystems and in their use of hypotheses, experiments, and explanations to organize their reasoning. Excerpts from their interviews, translated from Haitian Creole, illustrate the students' progress in developing conceptual knowledge and in using scientific thinking skills. (For a more complete discussion, see Rosebery, Warren & Conant, 1992.)

Photo credit: Ann S. Roseberry

A pond water sample viewed through the microscope.

Conceptual Knowledge. Not surprisingly, the students knew more about water pollution and aquatic ecosystems in June than they did in September. They were able to use this knowledge generatively in thinking through real world problems. In this example, Marie explains how she would clean the water in the Boston Harbor.

Interviewer:
What would you do first?
Marie:
I'd clean the water.
Interviewer:
You'd clean it? How?
Marie:
Like you look for the things, take the garbage out of the water, you put a screen to block all the paper and stuff, then you clean the water; you put chemical products in it to clean the water, and you'd take all the microscopic life out.
Interviewer:
What chemical products would you put in?
Marie:
Chlorine and alum, you put in the water.
Interviewer:
What would that do?
Marie:
They'd gather the little stuff, the little stuff would stick to the chemical products, and they would clean the water.

This example reflects the kinds of knowledge students used in the June interview. Marie described how she would rid the water of bacteria and other contaminants. She also outlined the process of flocculation used in the Cambridge treatment system, which she had learned about on a field trip several months earlier.

Scientific Thinking. Striking changes appeared in students' scientific reasoning from September to June. In September, we saw three ways in which the students showed little control of scientific forms of reasoning. First, the students' responses suggested that they did not understand the function of hypotheses or experiments in scientific inquiry. When asked for their ideas about what could be making the children sick, the students tended, with few exceptions, to respond with short, unelaborated, often untestable "hypotheses" that simply restated the phenomena described in the problem:

Interviewer:
Why do you think they all got sick at the same time?
Laure:
That's a thing.
Interviewer:
What kind of thing?
Laure:
Ah, I could say a person, some person that gave them something.
Interviewer:
I don't understand.
Laure:
Anything, like give poison to make his stomach hurt.

Second, the students conceptualized evidence as information they already knew, either through personal experience or second-hand sources rather than data produced through experimentation or observation. When asked to generate an experiment to justify a hypothesis (i.e., "How would you find out?"), they typically offered personal experience as evidence:

Interviewer:
...How would you know if it's that [the food]?
Marie Elsie:
I don't know. I think that what made them sick, it's because they [got] the food they gave them. Sometimes when I was in school, they gave me food I didn't like, and it didn't agree with, my stomach was, didn't agree with me, and then I got sick.

Third, the students interpreted an elicitation for an experiment ("How would you be sure?"; "How would you find out?") as a text comprehension question for which there was a "right" answer. They frequently responded with an explanation or assertion of knowledge and consistently marked their responses as explanatory ("because"). Here is an example.

Interviewer:
What do you think might have made the fish die?
Tony:
Because the garbage is a poison for them.
Interviewer:
How would you know it was the garbage that was making the foam and the fish die?
Tony:
The garbage made the fish die.
Interviewer:
How would you make sure?
Tony:
Because fish don't eat garbage. They eat plants under the water.

In June, however, the students showed that they had begun to understand the function of hypotheses and experiments and to reason within larger explanatory frameworks. Elinor demonstrated that she had developed a model of an integrated water system in which an action or event in one part of the system ("when it rains") had consequences for other parts ("the water will take the bad stuff and leave it in the river").

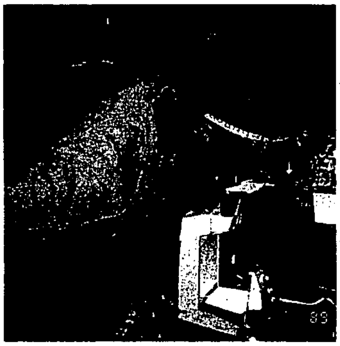
Photo credit: Ann S. Rosebery

A student examines water taken from the school's fountain.

Interviewer:
And what would you do with the bad stuff?
Elinor:
When you finish, you'd take it out, out of the machine.
Interviewer:
And where would you put it?
Elinor:
You can't leave it on the ground. If you leave it on the ground, the water that, the earth has water underground, it will still spoil the water underground. Or when it rains it will just take it and, when it rains, the water runs, it will take it and leave it in the river, in where the water goes in. Those things, poison things, you aren't supposed to leave it on the ground.

In June, the students no longer invoked anonymous agents, but put forward chains of hypotheses to explain phenomena. This is an example.

Interviewer:
What would you do to know what was making them sick?
Marie:
Like, you could test what the kids ate and, like, test the water, too; it could be the water that isn't good, that has microbes, that might have microscopic animals in it to make them sick.

The conditional language the students used in June (the "if's", "would's", and "could's") contrasts with the assertive yet vague language they used in September ("Because fish don't eat poison.").

The June interviews also showed that students had begun to develop a sense of the function and form of experimentation. This example shows how they no longer offered personal experience as evidence. Instead they proposed experiments to test specific hypotheses.

Laure:
I'd put a fish in fresh water and one fish in a water full of garbage. I'd give the fresh water fish food to eat and the other one in the nasty water, I'd give it food to eat to see if the fresh water, if the one in the fresh water would die with the food I gave it, if the one in the dirty water would die with the food I gave it.
Interviewer:
Would you give them the same food? What would you give the second one?
Laure:
The second one, yes. I would give them the same food to see if the things they eat in the water and the things I give them now, which will make them healthy and which wouldn't make them healthy.

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Interviewer:

... What do you think you would find?

Laure:

I see the one in the clean water might sooner not die than the one in the salty water, the dirty water. Because I think, I wouldn't have something in the dirty water and then see the one in the fresh water die and the other survive! I wouldn't believe that. I'd think the one in fresh water has more vitamins in it than that, because the one in the dirty water eats any garbage it finds under the water. The other one doesn't eat just anything, he only eats what I give him.

Laure outlined her experiment, specifying what she expected to find and why. In the process, she demonstrated that she had thought through the deductive consequences of her hypothesis and the implications of her experimental design. This phrase highlighted her growth: "The other one doesn't eat just anything, he only eats what I give him."

We noticed a subtle but important change from September to June in the voice the students used to respond to the interviewers' questions. In September, much of their discourse was enacted through the omniscient third person ("they put"; "they left"), with occasional uses of the first person to tell stories from personal experience. In June, a different voice emerged, as the preceding examples demonstrate: specifically an "I" that functions authoritatively as the voice of an active problem solver.

Cheche Konnen demonstrates the power of a sense-making approach for language minority students. Through this approach language minority students learn to think, talk, and act scientifically. Language mediates their learning in powerful ways. In the Water Taste Test, the students used both Haitian Creole and English to construct scientific meaning and communicate their understanding. Using Haitian Creole, they designed their studies, interpreted data, and argued theories. Using English, they collected data from their mainstream peers, read standards for interpreting test results, and reported their findings.

A sense-making approach may have an even greater effect than our results suggest. The seventh and eighth grade Haitian students were often isolated from the mainstream school community. But as they conducted the Water Taste Test, their mainstream peers saw them as doing something important and recognized them as experts on water quality. The teachers also took notice as the students talked about their investigation using technical terms, such as fecal coliform, with which the teachers themselves were unfamiliar. Most important, the students' developed confidence in their abilities and took a more critical stance toward knowledge. Their teacher, Josiane Hudicourt-Barnes, characterized the changes she observed in this way:

"I think that the kids' way of seeing the world, the way they think in general, has changed because they feel more comfortable learning on their own, investigating questions, thinking about questions and making them clearer, and finding out the answers whether from books or from experimentation. And most of all, I feel that they have made a step toward being critical about what people say to them... They're learning to find out for themselves and not listen to everything that they hear."

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An expanded version of this article appears in *The Journal of the Learning Sciences*, 1 (2), ©1992, Lawrence Erlbaum Associates, and in the TERC Working Papers, #1-92.

Dr. Ann S. Rosebery and Dr. Beth Warren are Co-directors of the Sense-Making in Biology in Language Minority Classrooms Project. Faith R. Conant and Josiane Hudicourt-Barnes are research associates on the project. This research began in 1988 in a Haitian bilingual combined 7th and 8th grade class and a multilingual, basic skills high school class. Since that time, it has expanded to Haitian-Creole and two-way, Spanish-English bilingual classes in grades 4-8.

Article 2

Social Identities, Moral Narratives,
Scientific Argumentation:
Science Talk in a Bilingual Classroom

ARTICLE 2: Social Identities, Moral Narratives, Scientific Argumentation: Science Talk in a Bilingual Classroom

Ballenger, C. (1997). Social identities, moral narratives, scientific argumentation: Science talk in a bilingual classroom. *Language and Education 11(1)*, 1-14.

Ballenger points out that the linguistic and social practices considered appropriate for school can appear to be foreign ways of talking and acting to many students. To understand how children learn to deal with multiple discourses as °they learn science, she proposes that detailed accounts by teachers and researchers are needed of teaching and learning in classrooms where this issue is being addressed. Her paper focuses on science discussion in a combined 5th- to 8th-grade Haitian Creole bilingual classroom. Ballenger argues that because the science discourse in this classroom included various genres of talk, such as story-telling and joking, it allowed many points of entry for children to participate. Their variety of ways of talking about science allowed them "to explore the content area, in this case, the growth of mold, in a way that led them well beyond the fairly simple and unproblematic explanations typically developed in school."

Questions

- In this article, Ballenger explores the connections between "everyday" (e.g. storytelling, joking) and "scientific" (e.g. impersonal accounts, expository talk) talk in a Haitian Creole bilingual classroom. She characterizes the way of talking about science that developed in this class and considers its role in learning science. How would *you* describe and characterize the way these children talk? Do you think that Ballenger makes her case that various genres of everyday talk such as storytelling and joking do, in fact, allow many points of entry for the students? Why or why not? Do you see these other genres of everyday talk in your classroom? What do you make of them, how do you respond to them? Does anything about the students' talk and activity as described seem "scientific" to you? What concerns, if any, do you have about this kind of talk and activity? What, if anything, do you think the students learned?

- Ballenger discusses the role the teachers' intentions and experiences played in the development of discussions in this classroom, and focuses on how the students and teacher shaped other students' contributions. In what ways do *you* see how the conversation was shaped? If you were the teacher, what other activities, if any, would you engage the students in to build on what they learned and how they were learning in science? How else might you imagine learning about your students' understanding from examining their talk in science?

Social Identities, Moral Narratives, Scientific Argumentation: Science Talk in a Bilingual Classroom

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This article explores a discussion in a class of Haitian students where a non-teacher-directed discussion format and an emphasis on the students' own questions encouraged the use of the students' everyday ways of talking and exploring ideas. The article addresses thc questions: will students unfamiliar with the discourse and practices of science more successfully engage in them, if they are able to bring more of their language and their everyday ways of making sense to the task? Or will the students in this case simply remain where they are, comfortable in a non-academic discourse, and unlikely to explore science as a different way of thinking and acting? Analysis of a discussion shows what and how the students are learning in this context. This is presented as a grounded example of what it might mean, in Bakhtin's terms, 'to populate' with one's own intentions a new discourse.

School is a site of many discourses, sets of linguistic and social practices that are considered appropriate ways to talk about books, to do maths, to regulate behaviour. Students arrive familiar with a variety of linguistic and social practices from their families and neighbourhoods. For some, school language is relatively close to what they know already and they comfortably join the various conversations. To others, it is difficult to gain access to what may appear to be very foreign ways of talking and acting (e.g. Ballenger, 1992; Boggs, 1985; Delpit, 1986; Gee, 1990; Heath, 1983; Michaels, 1985).

Science class is an area of schooling in which a variety of highly particular language practices hold sway. These language practices reflect the understanding prevalent in the classroom of scientific values, scientific ways of approaching the world and of making sense of it. Lemke (1990) has sampled the language used in high school and junior high school science classes and identified a large number of features which make up typical science classroom talk. According to Lemke, in order to talk appropriately in American science classrooms, students and teachers generally avoid the following: colloquial language; figurative language, 'emotional, colourful or value-laden words, hyperboles, and exaggeration', stories, humour, as well as 'personalities and reference to individual human beings and their actions' (p. 131–4). These features reflect the standard view of talk in science, that it should be impersonal and expository, and that development in the discipline involves moving away from any roots in personal or emotional response.

And yet many theorists of classroom life and language suggest that in excluding so many powerful aspects of communication, we are also excluding many students from participation (Gee, 1990; Michaels, 1985; Warren & Rosebery, 1995). Further, many argue that if the socioculturally situated speech forms that students bring to school with them are not honoured, then students receive the message that the ways in which they make sense of the world are not important and not to be brought to bear on school learning (Cazden, 1988; Freire, 1989; Gallas, 1995; Gee, 1990; Lemke, 1990; MacLean, 1994; O'Loughlin, 1992; Rosebery, Warren & Conant, 1992). The question remains, what is an effective response to these issues in the classroom? If it is true, as some educators claim, that students who are unfamiliar with the discourse and practices of school science will engage more readily with this new set of practices if they are able to bring more of themselves, their language and their everyday ways of making sense of their experience to the classroom, what will this engagement look like? How will we evaluate it? recognise it? Or, is it more often true, as others argue, that when students' everyday social and linguistic practices are honoured in the classroom, the students simply remain where they are, comfortable in a non-academic discourse, and unlikely to explore science as a different way of thinking and acting (Delpit, 1986; Gee, 1994)? Current reform efforts in science education, particularly those directed to issues of equity, require complex and grounded accounts of teaching and learning in classrooms where such issues are being addressed.

The purpose of this paper is to provide one such account, focused on science discussion in a bilingual science classroom, a classroom of Haitian students about whom I will speak in more detail below. I will attempt to characterise the way of talking about science that developed in this class, to consider what is different about it and its role in learning science. I will be arguing that because the discourse of science as it developed in this classroom includes various genres of talk, such as storytelling and joking, which are not typically a part of talk in the science classroom, but are a part of out-of-school talk, it allows for many points of entry for many different children. Thus in the discussion there were at play the reasoning and thinking of children who tend not to participate effectively in many aspects of school (cf. Gallas, 1994; Sylvan, in press). Further, I will argue that in these discussions the students were able to move into scientific genres of talk, specifically theorising, making scientific claims, interpreting evidence and generating investigations. Finally, I suggest that because they did so in ways which did not place these ways of talking and thinking in stark opposition to their out-of-school discourse, they were able to explore the content area (in this case, the growth of mould) in a way that led them well beyond the fairly simple and unproblematic explanations typically developed in school.

I will first introduce the students and their teachers; the teachers bring particular intentions and experiences to this work, and I will try to suggest the role these played in the development of these discussions. I will then present the texts and the story of the students' learning. Finally, I will consider the circumstances that supported the development of this way of talking about science.

The Context

The Classroom

These students had all arrived in the US from Haiti within the previous three years. They are children who come from backgrounds where religious explanation has generally been emphasised over scientific, and whose parents, while powerfully committed to an education for their children, have themselves had limited educational opportunities. They do not arrive with much background in science or much familiarity with the form of talk typical for science classrooms. These are not children who under typical classroom circumstances would be expected to do well in science (Lee, Fradd & Sutman, 1995; Oakes, 1985).

During the year in question they were 5th through 8th graders in a multigrade bilingual class in an urban school system. There was an English-speaking teacher, Patricia Berkley, who was primarily responsible for the 7th and 8th graders and a bilingual (Haitian Creole and English) Haitian teacher, Sylvio Hyppolite, who was primarily responsible for the 5th and 6th graders. The classes met together for science which was conducted in both Haitian Creole and English. The school-wide science teacher, Laura Sylvan, was also often present for science in this classroom and was a part of the planning. Science took place three times a week for approximately one hour.

The three teachers were also involved, with four other bilingual teachers, in a bi-monthly seminar series, part of the Chèche Konnen Project (Rosebery, Warren & Conant, 1992; Warren & Rosebery, in press). Chèche Konnen, which means 'search for knowledge' in Haitian Creole, is concerned with addressing issues of access to science learning for children in bilingual classes. In the seminar, researchers from the project collaborate with teachers in order to pursue questions that come from the students and to develop methods of investigation and experimentation that the students can use to pursue their questions. Using videotapes from the classrooms, the group then reflects on what they see there, attempting to explore what the students are learning. At the same time, teachers and researchers, with the help of a biologist, carry out investigations in natural science themselves, investigations prompted by the seminar participants' own questions. The teachers had spent the first year of the seminar exploring aquatic ecology in the seminar and in their classrooms; during this study they had learned about the subject matter, gained a sense of themselves as people who had the ability to do science (Warren & Rosebery, 1995), and gained experience both in formulating their own science questions, and in recognising and pursuing those that the students brought up.

During that year, Sylvio, the Haitian teacher, had developed a particular commitment to exploring the value of his students' everyday discourse in constructing scientific knowledge. As part of the seminar, he had watched a videotape of Haitian students arguing in another science class. Watching this talk closely, he saw that although they were arguing in some sense like they did at home or on the playground, they were nevertheless on topic and developing a serious critique of the methodology one of the students had used in a study of snail reproduction (Warren & Rosebery, in press). Haitian students are typically regarded as very quiet in class, in this country and in Haiti, and to this point, his students had been very quiet and respectful as well. Sylvio became committed to admitting this other kind of talk into his classroom.

Pat's experience of learning science in the seminar had opened up for her the possibility that her own way of thinking about the world, which in her education she had regarded as utterly unscientific, might have more value in developing scientific explanation than she had heretofore thought (Berkley, 1994). Laura, whose background in science was strong, remembered the pleasures of informal conversation about the natural world that she had experienced as a college student living in 'the science dorm'; but she felt that this kind of discourse was lacking in her science curriculum (Sylvan, in press). From various perspectives, and in various ways, all three teachers were committed to trying to use the students everyday talk and reasoning as a central part of the science curriculum for the following year. The discussions I will be exploring come from that year, the second year of the Chèche Konnen project.

Science Talks

The teachers decided to institute what they called 'science talks', after Gallas (1994, 1995). Science talks were whole-class discussions based upon experiences with phenomena such as mould, metamorphosis, skin colour — experiences which had taken place both in science class and in the wider world; like Gallas' talks, these discussions drew from experience and understandings formed outside school as well as from those that were a part of school. They were always a context for wide theorising: *kouman ou eksplike sa or reflèchi sou sa* ('how do you explain that?' or 'reflect on that') were common responses of the teacher to the children's contributions. Science talks developed several functions during that year. They were used by the teachers and the students to develop questions within the topic under study in science. The students, in small groups, would then pursue these questions in various ways — further observations, library research, experimentation. Later on in an investigation, science talks would be used to explore and to interpret the data or the explanations which had developed. Such discussions often led back into further study. The teachers might also call for a science talk if they sensed that there was not enough shared understanding about the questions the class was pursuing, about what they had understood, what they needed to do. Thus there was a continual interplay between small group and individual experiments or investigations and class-wide 'science talks'. These conversations generally took place in Haitian Creole, although more competent English speakers would at times switch back and forth.

Mould

When school began in the Fall in this particular year, one of the children, Joubert, told the class that in Haiti he had learned that if you left some cheese and a mango together for an unspecified period of time, a mouse would result. In the course of discussion, the teachers felt that there were a number of children who had some form of belief in spontaneous generation and so experiments were set up to test this. A mango and some cheese were placed in a jar, which was then lidded and taped shut. A number of children, who thought that sugar water would produce ants, left out little dishes of this in various corners of the classroom. One boy, Paul, surrounded his dish with flour so that he could determine if an ant walked to the water, rather than being produced by it. A number of girls combined various foods, flour, milk, rice, thinking to produce life. This work continued as a backdrop to other experiments until February when the failure of a mouse or ants to appear led the children to discard the idea.

Early on in this investigation, however, the class had discovered mould. Two girls had created individual mixtures of flour, water, milk, and sugar, testing at that time whether or not ants or flies might develop. After a week, the mixture in one dish was wet and had green mould on it; the mixture in the other was rather hard and dry and had no mould. The children with their teachers had a series of discussions about what could have caused this difference. This was the beginning of a six-month long series of investigations into mould which came to include experiments and observations, reading and individual science fair exhibits.

The children asked whether or not mould was alive, and what were relevant criteria to make this distinction. Some children set out to determine if it ate, as a way to know if it was alive; others tried to determine if it grew. They considered under what conditions it developed, and in particular the role of moisture and heat. Robert, for example, found out that the more drops of water he put on his various pieces of bread, the faster mould developed there. Joseph and Pierre showed that their pieces of bread with mould growing on them lost weight over time. They suggested that the mould appeared to be eating the bread.

I will turn now to consider in some detail one science talk on the topic of mould. I will consider this talk in relation to the following questions: What was the nature of this talk, how was it different from standard talk in science classrooms, and what were the children learning from their participation in it?

The Texts

The following transcript was chosen because it was representative of the kind of exciting and engaged discussion typical of this classroom. The students' names have been changed. After the initial investigation of mould had begun, Sylvio Hyppolite, the Haitian teacher, asked the children to consider where and under what conditions they usually find mould. Many claimed that it is generally in wet places, in particular in the bathroom. Manuelle's voice then chimes in disapprovingly:

Manuelle: Because they just leave stuff there, take no care, they don't clean, they just [ ] if you have a toilet in Haiti, you take care of it, it won't have mould. (*Paske yo just kite bay la yo pa pran swen yo, yo pa clean yo just [ ] si ou gen yon twalèt Ayiti, ou pran swen li li pap fe limon.*)

Sylvio: Children, let me say something. OK, all right, she said that [her toilet] doesn't make mould. You, you said you don't agree. Explain. (*Timoun, kite m di yon bagay. [ ] OK all right [ ] li di [ ] pa fè limon. Ou menm ou di ou pa dako. Eksplike* [ ])

Student: Toilets make mould! (*Twalet fe limon!*)

Manuelle: Not all. (*E pa tout.*)

Sylvio: How do you explain? (*Koman eksplike?*)

Student: [ ] toilet downstairs has mould. ([ ] *twalet anba fè limon.*)

Student: [ ] clean it. ([ ] *clean li.*)

Manuelle then reclaims the floor.

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Manuelle: OK. What I told you, I told you, MY TOILET at MY HOUSE doesn't have mould because I CLEAN it! (*E ben, sa m di ou la, m di ou, mwen menm twalèt lakay mwen pa fè limon paske m clean li!*)
Student: All toilets have mould. (*Tout twalèt fè limon.*)
Manuelle: Not all. (*E pa tout!*)

Another student, Marc, after giving Manuelle credit for her claim, proposes to test it with an experiment.

Marc: That makes that, it doesn't have mould, it's because she always washes at her house, if she didn't. We ought to do an experiment. (*Sa k fè sa, li pa fè limon, e paske li toujou lave lakay li, si li pat. Se pou fè eksperyans.*)

He proposes an experiment in which you wash one shower curtain, you dont wash another, and then you see where mould grows. Commotion ensues as the students disagree about what will happen. Many, presumably who come from families where the bathroom is washed and the shower curtain gets mouldy nevertheless, seem to dismiss the power of washing. The discussion continues with the teacher asking them: 'Suppose that you don't clean the toilet, will you have mould in the toilet?' Again, most students agree that you will, although they begin to disagree about whether any water will make mould or whether it has to be dirty water. Eventually Joanne returns the discussion to the necessities of housework.

Joanne: At home, we usually, Monday, Tuesday, Wednesday, we usually [ ] clean the bathroom in, if you see where people go to the toilet, it is starting to be yellow inside, then you clean it, when you clean it it's hard to get it all out, you have to use clorox, [ ] it's that [ ] mould begins to appear. (*Lan kay la, nou konn fè, lendi, madi mekredi, nou konn fè [ ] clean bathroom nan, si ou wè kote moun al nan twalèt la, li komanse jon andan, se le ou clean li, lè ou clean li li difisil pou ou retire, se Clorox pou ou mete [ ] es se sa [ ] limon komanse p[r]al fet.*)

Personal values and the discourse of science

Let me try to characterise here the difference I see in the style of talk the Haitian children are employing from what is more typical of science classrooms. Manuelle, who is a 6th grader with a good deal of social and rhetorical power, is using an informal, argumentative style: '*eh ben sa m di ou la* / ok, let me tell you what I said'. And she is asserting herself, '*mamem, lakay mwen* / ME, AT MY HOUSE we don't have mould'. She is using a somewhat moral language: '*pran swen* / take care' is what you should do; 'just kite yo / just leave them' is clearly what you should not. She is telling the group something about mould that she knows — that it does not grow in every bathroom — and at the same time she is telling the others something about herself. She is strongly advocating both aspects — that she knows how to clean — in evident contrast to some people — and that bathrooms do not grow mould under all conditions.

Joanne continues with the same subject. Joanne's style is less assertive than Manuelle's. She uses a sort of list intonation, detailing the job — the days of the week, when you know you must clean, and what you must use. She makes it clear that she knows rather precisely how to clean. And she implies that if it is not done right, there will be mould. She, too, is telling us something about herself and her views of proper behaviour at the same time as she discusses the conditions for the growth of mould.

While these children are presenting evidence from their experience on where mould grows, it is also clear that they are presenting this evidence in relation to themselves. There are, in fact, moments in this transcript when the object of discussion, what we might call 'the science topic', appears quite confounded with what we might call the personal and moral content. For example, when Manuelle asserts, 'what I'm telling you is my toilet doesn't have mould [ ]', and Joanne as she intones 'at home, we usually, Monday, Tuesday, Wednesday, we usually clean the bathroom', it seems unclear who is being addressed — someone who doesn't understand the value of cleanliness the way the speaker does, or someone who doesn't understand about mould. And yet note the further discussion. No one responds directly to whether or not Manuelle is clean; or whether or not it is important that she should be; rather they respond to what she says about bathrooms. 'All toilets have mould', the kids assert in the end of the segment with Mendette. 'Not all', repeats Manuelle. Marc then proposes an experimental test. And yet, Manuelle's tone is not lost or overridden. Joanne's response continues the personal quality of Mendette's, as do others who enter later.

Different discourses are in contact here, different ways of talking, different values and approaches to knowledge are bumping up against each other. For many, talk about domestic routines exists primarily in a moral language; for Manuelle her claim seems to be as much about her cleanliness as it is about mould. And yet by making this claim she distinguishes herself from the other students, who accept the generalisation that all bathrooms grow mould, and in doing so she sets up the contrast which Marc then uses to propose an experiment. When some children disagree with Manuelle, Joanne enters to delineate further the concept of cleaning — perhaps these students don't know what good cleaning really is. She gets down to specifics and explains the timing and materials which make up good cleaning. In the process cleaning is opened up slightly as a concept to include these particular features. By focusing on the materials and the timing of cleaning, on the methodology, she is making no less of a moral argument — you still have to do it right — but this sort of move towards specification is a prerequisite to the development of an investigable question, in science and in everyday argument (Ochs *et al.*, 1992).

Narrative and the discourse of science

Let us consider a case, slightly later in the same discussion, where the personal and moral claims the students are making about themselves and the claims they are making about mould are disentangled to some extent. Sylvio, the teacher, has been directing the children to contrast the living room with the bathroom. The students have stated that the living room does not have mould in it, principally they feel because there is no water there. Joseph counters this consensus.

Joseph: Mr Hypolite. [ ] at my house, in the living room, under the window [ ], we always put food under the window. I know when [ ] the

oatmeal, the oatmeal [ ] under, in the living room, when my dad made oatmeal, a little bit of oatmeal fell out, when he put it hot under the window, it got out, into the window, like, when my father made oatmeal, a little bit of oatmeal fell out.
One day, one day, I turned up there.
When I looked, I saw, I saw a little green thing in the screen with [ ]
(*Mr Hypolite. [ ] lakay mwen, nan salon lan, lakay m nan, nou toujou met manje sou fenèt lan, kom si, m konnen, nou, lè papa m fè labwi, labwi a, ti kras nan labwi a vole, lè l mete cho sou fenèt la, li soti, andann fenet lan, konm si la, lè papa m fè labwi, on ti kras labwi jete.*
Yon jou konsa, yon jou konsa m parèt.
M we ti bay vèt nan gri ansanm avek [ ])

Students: Ohohoh
Jimmy: With, under the window and I took it out, I took a knife, I took it out, I cleaned it. (*Sou kote fenèt la [ ]. M retire l, m pran on kouto, m retire li, m clean li.*)
Sylvio: Where did the thing come from? Where did it come from? (Kote bay sa soti? Kote sa soti?)
Jimmy: From food. Because I saw that the food was there a real long time and then it came. (*Nan manje! Paske m wè manje a fè yon paket tan [ ] e li soti?*)
Caroline: You see why room, um, what, living rooms can't make mould? Because [ ] you have to clean your room every day. (*Ou wè pouki chanm, um, ki sa, salon pa ka fè limon? Paske [ ] pou clean chanm ou chak jou.*)
Students: Yeah, the living room, really. (*Salon wi.*)
Rachel: Mr Hypolite, Jimmy said that it's food that makes mould. Well, if I eat some food, will I have mould inside me? (*M. Hypolite, Jimmy di konsa e manje a ki fè limon. E ben, si m manje yon manje la, m gen limon andan m?*)
Students: No ha ha ha

In his account, as in Joanne and Mendette's, what Joseph is saying about the 'science topic', in this case the point being made about where mould can grow, is again in some complicated relation with what he also wants to say about himself. He uses a narrative to make his point(s). Consider his story. He gives us the setting: my house, under the window. He mentions his father's custom of setting the oatmeal to cool under the window. And then he turns to the event: One day he turned up there and he saw a little green thing in the screen. The phrase 'little green thing' receives emphasis in his shift to a high-pitched rapid delivery. Clearly one of the points of telling the story is that there was mould growing there and that it — this he tells us with his intonation — was yucky. The kids respond by squealing. However he does not stop there. Without pause he continues in rapid-fire rhythm with: 'I took it out. I got a knife. I took it out. I cleaned it.'

I would propose that he finishes off his story the way he does in order to ally himself with the other cleaners, Manuelle and Joanne; he articulates his membership in this community of clean children who keep mould from various areas of the home. It is perhaps for this reason that he uses 'clean' in English the way the two girls do, instead of the Creole word *'netwaye'*, which his teacher used in asking the initial question. Or perhaps he ends his story the way he does in order to save face — having presented his house as dirty, he must return us to a world with a responsible boy and a clean house. In any case, it seems to be a social need that dictates the ending he chooses. It has to do with the self he is presenting, not the evidence on the conditions necessary for the growth of mould.

However, in the ensuing discussion, Joseph is shown by his teacher and his peers other ways that he might have finished his story. He is shown that, while he may tell stories in these science discussions, their purpose in this context is not only a social one. First Sylvio, the teacher, asks where the mould came from; it is a little unclear whether Sylvio knows and is asking Joseph to state this more clearly for others or whether Sylvio himself is wondering what this story may have to offer a theory of mould. By answering that the mould came from food, Joseph makes explicit one meaning for his story in the discussion, one that he had not articulated directly: the mould was in the living room because food had been left there. Then Caroline enters the discussion. She seems to be saying that this story just goes to show that you have to clean the living room. She is making explicit the connection between Joseph's story and the preceding conversation about cleaning the bathrooms and the consequent absence of mould. She has rarely spoken in science discussion before this point. Like Manuellee and Joanne, her knowledge of domestic routine gives her a point of entry into the discussion. Rachel next responds to the crux of this argument which Joseph and Sylvio together have articulated. She first restates the claim as it has appeared in this discussion — that food can make mould — and then, by invoking the logical consequence, that she must have mould inside her since she eats food, she challenges it. The children laugh.

The responses Joseph receives provide him with a new version of his narrative, one in which different aspects are explicitly foregrounded. Sylvio's, Caroline's, and Rachel's responses, all speak to aspects of the science topic, highlighting and articulating and challenging aspects of the narrative's meaning in relation to the argument. Sylvio and Caroline, by their questioning and modelling, demonstrate that he must make the connection between his narrative and the science topic explicit, that that is how one argues in this context. Rachel then takes Joseph's narrative as a claim, further explicating the function of such a story in a science discussion The children are providing a response to a narrative of mould, not a narrative of Joseph.

What Has Been Learned?

Recent work in the social study of science suggests that within the scientific profession itself, personal content (for example, the interests and values of the scientist) are present in various stages of a scientist's practical work and theorising, but are in the public product generally absent or at least not made explicit (Latour, 1987; Lynch, 1985). In this discussion, Manuelle and Joanne, as we saw earlier, are determined to discuss mould against the backdrop of a highly important personal value, their own cleanliness. Joseph is struggling to incorporate his own story on this issue and his argument about mould. Rachel articulates the claim she sees in his story — she uses logic to explore further implications; at the same time, however, her utterance is a joke. The participants' responses shape the way the various contributions are understood in the context of the science argument, but the social intentions remain enmeshed in the arguing and theorising. These children are acquiring ways of arguing, developing and interpreting evidence and theorising in a scientific discussion, but without moving away from their social intentions as well.

I would also claim that these students learned a great deal about mould, and learned it in a way which created further curiosity. My evidence for their learning comes from the questions they asked at the end of this unit. Typically, at the end of a unit in school, children are aware of no further questions. And yet what they have learned in any particular area is generally only the beginning of an understanding from the point of view of the discipline itself. After many science talks like the one above, and after following their own questions by means of experimentation, observation and some work with texts, these children were asked to state both what they had learned and what they still wanted to know. What they could recount was quite impressive; some of them were able to go on in a detailed manner about spores and stems and roots and sequences of colours, but equally striking were their questions. Jackson, when I asked him what he had learned, laughed and answered in Creole, 'It's not what I learned. I have a question to ask you'. He then asked, 'How did the mould manage to become green, it became yellow, white, black, brown?' (*'Se pa aprann m ap aprann. M gen on kesyon pou ou. Ki jan mould la fè vin vèt, li vin yellow, jon, blan, nwa, mawon?'*) Manuelle asked why the white fuzzy stuff which precedes the growth of green mould in the classroom doesn't seem to do so in the bathroom, here or in Haiti. Pierre asked why there are so many different kinds of mould. Joanne wanted to know how water helps mould to grow, what actually happens. When it is the science specialist's turn, she tells the class that what she still wants to know is, does mould grow inside of you?

There is a high level of engagement, a strong desire to know in these questions. But more than that, these are fundamental questions. Science in schools often ends with knowledge like, water is necessary for mould to grow. What Joanne is asking, is how. Jackson is laughing, pleased with himself, and asking a similar question — how do these colours develop? They are, I believe, attempting to imagine these processes, certainly a powerful way to engage with scientific explanation; for this purpose, they are not satisfied with the level of explanation they have. The questions and investigations the students began with have generated new ones, including one compelling enough to prompt the curiosity of the science teacher. She has taken on Rachel's joke, out of Joseph's story, as the science question she most wants to follow.

The Structure of Science Talk

As we have seen, this discussion contains a great deal that is personal, rhetorical, moral, and domestic; it takes a form not typical for serious science class discussion, e.g. jokes, stories, personal claims about cleanliness. And yet this is a serious discussion on mould. Jokes and narratives and accounts of domestic routine are regarded as acceptable forms of participation in this conversation.

Students find different routes to enter the discussion, and many children enter the discussion who otherwise might not.

Discourses are in contact here. They include academic and personal intentions, sometimes fused. But, as we have seen, these contributions are not left to stand without response. Joseph's fellow students are helping him to see his narrative as part of a reasoned argument about mould, but at the same time they are doing so without asking him to abandon the more personal intentions contained in his story, intentions which include value judgments, self-expression and emotional response. The children respond to Manuelle's argument about her clean bathroom as an argument about mould and the conditions under which it grows (they propose to test this argument) but they also hear her claim about her personal cleanliness. The language in which the students organise and present their knowledge here includes these stories of domestic routine; but in its reception there is a reshaping. As they are jointly working out the relationship of the various contributions to the question about where mould grows, they are developing ways of arguing, evaluating evidence, designing experiments and theorising appropriate to scientific discussion.

It is important to recognise that it is the response in discussion that functions to do this. The nature of the response is often ignored in studies focused on the use of academic and non-academic discourses in school. Martin (1992), for example, claims that using narrative in classroom science does not lead children to develop their ability in more standard scientific ways of talking; however, he does not look at the response the children receive to their narratives.

In the nature of the responses students receive and in who is allowed to make them, we see that the 'science talks' discussed here included a different set of speaking practices than exist in most classrooms. As Cazden and others have pointed out, the format of most lessons typically falls into what has been termed 'the default script' (Cazden, 1988), a monologic and scripted kind of talk in which teachers pose the questions and evaluate the replies. This standard way in which participation is orchestrated, although quite possibly useful in some teaching situations (Wells, 1993), serves as a powerful impediment to authentic conversations in which multiple perspectives, students' and teacher's, come into contact. Nevertheless, various teachers and researchers have commented on how difficult it is to avoid returning to this format (Gallas, 1994; Mehan, 1979; Gutierrez, Rymes & Larson, 1995; Wells, 1993).

Perhaps most important in altering this standard structure of classroom discussion was the effect of following students' questions on the forms of participation. When the questions came from the students, the teachers were often hard-pressed to fully understand the question. They had to turn to the questioner as the expert who had the opportunity to elaborate: thus the location of knowledge shifted from teacher to student in these instances. The nature of the talk often shifted as well, from the 'final draft' genre typically used in answering a teacher to more of an 'exploratory' one (Barnes, 1976). Once the standard formats for talk were turned around in this way, students found it reasonable to address the claims and comments of other students directly, instead of always addressing their comments to the teacher. Authentic questions from the teacher created the environment in which a variety of responses and respondents were possible. As Sylvio has said, in general he was trying to learn along with the students, rather than orchestrate a discussion towards a predetermined agenda.

At the same time, there were also many instances in which teachers did answer questions, both with information and with proposals about how to find out. But in this case the responses often took place over extended periods of time. For example, there were questions which teachers brought to the teachers' seminar for consideration before responding; other questions which they remembered later, or came to understand later, but which they had missed in the moment and had to bring up again; others which they realised they had reshaped to their own meaning in their initial classroom response and which therefore they had to return to as well. The use of videotape often gave the teachers a second chance to understand what students were grappling with, a chance free from the pressures of the moment, and new questions as well as new understandings were uncovered, new responses developed by this means. The conversations in the seminar were a crucial scaffold for thinking about students' meanings in this way; they allowed for lengthy probing of a student's idea or question. They came to represent a space in which meaning was not simple or obvious, in which everyone's contribution was scrutinised for the sense it contained.

Conclusion

Bakhtin describes the process of acquiring a new discourse as 'populating' it with one's own intentions and purposes (Bakhtin, 1981). I have attempted here to contribute to the discussion of what it might look like to do this. The quality of personal expressiveness, the intentions that have to do with presenting one's self, one's values, one's questions and one's outlook, are the serious intentions the children come with, with which they populate the discourse of science. I would suggest that discussions like this in which these intentions are neither denied, nor simply tolerated, but where instead they form part of a richly layered kind of talk, with multiple strands of meaning and intention, of remark and response, is of central importance to the process of entry into a new discourse.

We now know something about how these children's ways of talking science have changed over time. Is Manuelle less likely to bring her personal cleanliness into the discussion as time goes on? Does Joseph more explicitly link his story to the argument? Data from the end of the third year of the project suggest that both Manuelle and Joseph are changing in these ways, as well as others. Has the tone of their engagement with phenomena and explanations become less personal, less expressive? Certainly one imagines that Manuelle, if she goes on in science, will see the argument as less directed towards people who may not recognise how important it is to be clean. This says nothing, however, about the possible persistence of the moral and personal frames for knowledge that Manuelle and the others employ. One wonders if one source of the highly personal and resonant connection that many scientists exhibit towards their work, the approach that Einstein refers to as 'intuition resting on sympathetic understanding' (Fox-Keller, 1983: 201) or what Barbara McClintock calls 'a feeling for the organism' might not be in the sort of talk which allows the speaker to put into contact deeply held values and personal concerns with what he or she knows or is considering about scientific phenomena.

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Article 3

A Communication Framework for Mathematics: Exemplary Instruction for Culturally and Linguistically Diverse Students

Article 3

ARTICLE 3: A Communication Framework for Mathematics: Exemplary Instruction for Culturally and Linguistically Diverse Students

Brenner, M.E. (1994). A communication framework for mathematics: Exemplary Instruction for culturally and linguistically diverse students.
In B. McLeod (Ed.), *Language and Learning: Educating Linguistically Diverse Students*, 233-267. Albany, NY: State University of New York Press.

Brenner presents a view of mathematics teaching and learning that emphasizes effective communication as a bridge between culturally and linguistically diverse student populations and mathematics. Her emphasis on communication builds on the notion that all learning takes place within a social context, and that effective mathematics learning is a process of enculturation into the discipline. Changing norms of classroom discourse have been emphasized by the mathematics reform movement, norms that include active student participation and multiple forms of discourse, among others. Brenner provides student-based examples from anthropological studies which show ways in which students, particularly linguistically and culturally diverse students, gain entry into and participate in a wider range of discourses. Finally, she moves beyond the classroom to consider how curriculum and institutional environments can contribute to facilitating communication in mathematics classrooms.

Questions

- Brenner outlines what she refers to as a "Communication Framework for Mathematics." Spend a few minutes reviewing Brenner's discussion of current theories of learning which she suggests provide a rationale for encouraging communication in mathematics. Is there anything in this work that surprises you or that is new for you? What, if anything, does this make you think about in your own experience as a learner? As a teacher?

- Brenner discusses Communicating *About* Mathematics, *In* Mathematics, and *With* Mathematics. What do you think she means by each of these? Give some examples from the article of each type of communication. Can you identify any examples from your own mathematics teaching practice that might fit these categories? Do you find these to be helpful ways of thinking about communication in mathematics? Why or why not?

- Brenner outlines three different kinds of contexts for improving mathematics communication, Curricular, Instructional and Institutional. What do you think she means by each kind of context? Are you familiar with any of the examples she points to? How do these contexts relate to your teaching situation? Does this discussion of different kinds of contexts open up any perspectives for you on your teaching?

- What relationships, if any, do you see between what Brenner has to say about communication in mathematics and the teaching of science?

A Communication Framework for Mathematics: Exemplary Instruction for Culturally and Linguistically Diverse Students

Mary E. Brenner

The sad truth is that in American schools there is little communication taking place in mathematics classrooms. Stodolsky's (1988) study of fifth grade classrooms found that students worked by themselves more often than they engaged in any other activity. Individual seatwork comprised 40 percent of students' class time. About 30 percent of the time students and teachers participated in recitations in which teachers posed close ended questions and students gave brief responses. Open ended discussion took up less than 1 percent of class time. The picture may be even bleaker for children who are culturally and linguistically different. The Study of Academic Instruction for Disadvantaged Students (Knapp et al., 1991) observed that fully half of each class period was spent on individual work. Teacher lectures occurred in slightly more than half of the class days. Teacher-student discussions took place in only about one out of three class sessions, and these were mostly recitations of the sort described by Stodolsky.

Within the context of such classrooms, the available opportunities for communication are fewer for many students. Students with limited command of English may be less able to learn from formal teacher lectures and recitations than other students (Cummins, 1981) because they have not yet mastered formal discourse styles. Students from some cultures, particularly Native American students and African American students, find the stilted discussion style typical of mathematics recitations particularly shaming or meaningless (Heath, 1983; Philips, 1972). Other students believe their peers are more effective role models for mathematics than the teacher but they have little opportunity to interact with other students (Kagan, 1986; Lave, 1990).

It is particularly important to examine the forms of communication in mathematics for the language minority child in late elementary and junior high school. In addition to coping with cultural differences in communication style, children of this age are typically making the transition from dominant language instruction to English dominant classrooms. In both early and late bilingual transition programs the child begins to receive some instruction in English between grades 4 and 8. In a number of schools this transition occurs first in mathematics in the mistaken belief that mathematics is a universal language or entails minimal language use. As Cummins (1981) points out, the criteria for this transition typically rest upon a child's conversational skills in English. But academic discourse skills take years longer to develop, and mathematics instruction has its own particular forms of discourse that are now being systematically described (Durkin and Shire, 1991; Pimm, 1987). The difficulty of the transition to mathematics instruction in English may be the cause of the higher levels of test anxiety in mathematics that have been found for bilingual Latino children when compared to their peers who are still Spanish dominant or come from English speaking homes (Willig, Harnisch, Hill, & Maehr, 1983).

The late elementary and middle school years are critical to later mathematical achievement for all children because attitudes towards mathematics form in this age range and de facto tracking becomes a reality in many junior high schools. By fifth grade children have formed realistic self-concepts of mathematics ability that endure into high school (Newman, 1984). Generally positive attitudes towards mathematics by both females and minority students in the early elementary years decline significantly during the later elementary and junior high years (Anderson, Thorpe, & Clewell, 1989). In turn these negative attitudes lead to lower achievement for female students and a reduced likelihood of taking college preparatory mathematics for both females and minority students. Junior high also marks the turning point in the availability of mathematics classes and the tracking of students into different kinds of mathematics courses. While elementary schools have relatively equal amounts of time devoted to mathematics regardless of the composition of the student body, junior high schools serving predominantly minority students have fewer course offerings in mathematics (Oakes, 1990). Even within the same school, minority students tend to be tracked into lower level classes (Moses, Kamii, Swap, & Howard, 1989; MacCorquodale, 1988) as do female students. The effect is compounded for at least some groups of minority females such as Mexican American women who are the least likely group of all to take pre-algebra in junior high (MacCorquodale, 1988) when compared to Anglo males and females and Mexican American males in the same schools. Although the situation has been less systematically assessed for students with limited proficiency in English, it appears that mathematics instruction is also more limited for this group. In the elementary years this is often due to increased time spent on language instruction while at higher levels there are limitations in the number of bilingual mathematics teachers and materials in languages other than English.

The model of exemplary mathematics instruction proposed in this paper emphasizes effective communication as the intersection between the kinds of mathematics that we want students to learn and the ways in which we can reach culturally and linguistically diverse student populations. The paper begins with a brief overview of the mathematics reform movement and the role of communication within it. The rationale for emphasizing communication as a mathematical goal is further elaborated by drawing upon social constructivist theories of learning and anthropological studies of classrooms. An overview is then given of the Communication Framework for Mathematics. The details of the Framework are presented with examples of specific educational practices that have been used with diverse student populations in grades 4 to 8. The paper concludes with a consideration of how other aspects of the school context, including curriculum, instruction and institutional support, can enhance effective mathematics communication.

Background

The kind of instruction described by Stodolsky (1988) and Knapp et al. (1991) is based on transmissionist models of how students learn. In this model the teacher has mathematical knowledge which she dispenses to the students through lectures and modeling of mathematical procedures. The student's role is to then individually practice mathematical skills during seatwork and homework assignments. By the early 1980s many mathematics educators were convinced that traditional mathematics instruction was failing both the majority of students and the nation (National Council of Teachers of Mathematics, 1980; National Research Council, 1989). Although some students flourish under traditional instructional methods, most students do not. A report by the National Research Council states "Mathematics is the worst curricular villain in driving students to failure in school. When mathematics acts as a filter, it not only filters students out of careers, but frequently out of school itself" (1989, p. 7).

A number of problems follow from the low level of student achievement in mathematics (National Council of Teachers of Mathematics, 1989). Most students take only one year of high school mathematics. Consequently, not enough students are adequately prepared in mathematics to pursue technical professions, and women and minority students are particularly underrepresented in technical areas. Even jobs which do not traditionally require much skill in mathematics are becoming transformed as the United States moves from being an industrial society to an information society. Correspondingly, the American people need a higher level of mathematical literacy to deal with the new society and increasingly complex social problems. The mathematics reform movement arose in response to these problems and has advocated a complete rethinking of mathematics education as documented at both the national (National Council of Teachers of Mathematics 1980, 1989, 1991) and state level (e.g. California Department of Education, 1992).

In addition to prescribing more mathematics instruction and a revised set of mathematical topics at all levels of elementary and secondary school, the mathematics reform movement advocates a different vision of the mathematics learner. "Rather than being passive absorbers of knowledge, children actively create their own understanding of the world. In fact, by the time they come to school, they have already developed a rich body of knowledge about the world around them, including well-developed, informal systems of mathematics." (California Department of Education, 1992, pp. 32–33). The constructivist learner is explicitly believed to need active communication activities as part of the learning process. "Communication plays an important role in helping children construct links between their informal, intuitive notions and the abstract language and symbolism of mathematics" (National Council of Teachers of Mathematics, 1989, p. 26). In addition to helping children connect their old and new knowledge, the communication process enhances independent mathematical reasoning: "Emphasizing communication in a mathematics classroom helps shift the classroom from an environment in which students are totally dependent on the teacher to one in which students assume more responsibility for validating their own thinking" (National Council of Teachers of Mathematics, 1989, p. 79).

The emphasis upon communication derives from the recognition that learning proceeds most effectively within a social context. The social constructivist perspective has influenced current conceptualizations of mathematics learning through three distinct traditions. Vygotsky (1978) posited that learning takes place when the learner first collaborates with an adult or more competent peer to accomplish a task just beyond the learner's level of independent functioning, within the "zone of proximal development." What is accomplished in a social context is then internalized for individual mastery. Effective adult guidance of learning has been described as scaffolding or proleptic teaching in which the teacher is sensitive to the learner's current level of functioning and structures learning to take place within the zone of proximal development. Peer collaboration also can be effective in this perspective if there are joint goals and active dialogue about reasoning processes (Tudge, 1990).

Neo-Piagetian research provides a different perspective on the role of peers in the learning process. Rather than stressing the relative competencies of the peers, this line of research emphasizes that peers bring different pieces to the learning situation, some of which are complementary, some of which are conflicting. Sociocognitive conflict between peers of different levels of functioning can stimulate cognitive growth without the active peer tutoring implied in the Vygotskian model (Doise and Mugny, 1984). Growth can also occur when learners with different perspectives but equal competency "help each other incorporate new problem-attack and reasoning strategies into their repertoire" (Forman, 1989, p. 67). Cooperative collaboration of this sort enables students to accomplish tasks that may be beyond the competency of any individual participant.

The final socially based perspective views optimal mathematics learning as a process of enculturation (Bishop, 1991; Lampert, 1990; Schoenfeld, 1992). From this point of view, the learner enters into a community of practice with the ultimate goal of learning to think and act like a member of that community. Lampert (1990) compares school practices to descriptions of mathematical practice. School practices typically consist of learning a set of rules and skills and then applying them to various problems assigned by the teacher. In contrast, mathematical practice entails making conjectures and then devising mathematical arguments to support them. Developing mathematical practice in the classroom requires that different kinds of discourse occur, particularly an expansion in the student role during classroom discussions. The teacher's role changes as well to encompass doing mathematical discourse with students as well as acting as a guide to mathematical conventions and presenting a model of how to do mathematics.

While social constructivist theories of learning demonstrate the social interactional basis of learning, anthropological studies of schooling strongly suggest that forms of communication in classrooms need to be changed to enable all children to effectively participate. Work by Heath (1983), Jordan (1985), Au and Mason (1981) and Philips (1972) demonstrates the ways in which current styles of classroom organization have systematically blocked children from some cultural backgrounds from participating in classroom interactions. Philips (1972) introduced the idea of a participant structure, which she defined as the way in which interactions are organized. Participant structures vary along dimensions of how many students participate, who has the right to set the topic, who has the right to determine the speaker, who the audience is and so on. When the participant structures from home and from school differ substantially, students become reluctant to participate. In Philips' study, Native American students were uncomfortable in situations in which they had to speak alone in front of their peers and when the teacher designated whose turn it was to speak. Native Hawaiian children are also reluctant to participate in large group lessons. They are more apt to participate when the teacher shares control of small group discussion (Au and Mason, 1981) or when they are allowed to work with peers (Jordan, 1985). The educational changes inspired from this work have changed classroom participant structures to be more congruent with home participant structures, although they are not necessarily identical.

Heath's (1983) work with African American and working-class White students has shown how other incongruencies between home and school communication contribute to classroom problems. Teachers often use forms of questions which are totally alien or unanswerable to children of other cultural traditions. At home children learn to respond to certain kinds of questions, are systematically taught to ignore other kinds of questions and are simply not exposed to other types. Heath worked with teachers to help them to become aware of such communication differences and to build from the strengths children brought with them to school. At the same time materials were developed to explicitly teach children the differences between their natal forms of communication and school communication with a goal of gaining mastery over school forms of discourse.

Although most of the work on developing culturally compatible forms of communication in classrooms has focused on literacy training, many of these same instructional insights can be applied in mathematics classes. For instance, the work with Native Hawaiian children in the Kamehameha Early Education Program described above (Au and Mason, 1981; Jordan, 1985) has been applied by teachers in their mathematics instruction, resulting in clear improvement in mathematics achievement (Brenner, 1984, 1985). However, many teachers who readily change their language arts instruction are less likely to do so in mathematics until they change their beliefs about the nature of mathematical knowledge and what students should be doing in mathematics classrooms (e.g. Lampert, 1990; Wood, Cobb, & Yackel, 1991).

As outlined above, the emphasis upon communication in mathematics classrooms has support from current theories of learning and anthropological studies of classrooms. The nature of mathematical communication needs to be further elaborated in order to enable educators to implement pedagogies which support both mathematical learning and effective participation of students from diverse linguistic and cultural backgrounds. The next section of this paper describes the Communication Framework for Mathematics. The Framework provides a structure to examine the ways that classrooms should and can function effectively for diverse student populations.

Communication Framework: Overview

The Communication Framework for Mathematics attempts to systematically describe in detail the kinds of communication which are advocated in more general terms by the mathematics reform movement. Three of the six standards for instruction set by the National Council for Teachers of Mathematics (NCTM) (1991) directly deal with classroom discourse and the other three do so indirectly as shown in Figure 8.1.

Figure 8.1 NCTM Standards for Teaching Mathematics

Tasks
1. Worthwhile mathematical tasks

Discourse
2. Teacher orchestrates discourse
3. Active student participation
4. Multiple forms of discourse

Learning Environment
5. Teacher creates rich and challenging learning environment

Analysis of Teaching and Learning
6. Teacher monitors students' learning as basis of planning

Source: National Council of Teachers of Mathematics (1991). Paraphrased from pages 19–67.

Standard 2 emphasizes the teacher's role as orchestrator of diverse forms of discourse in the classroom. Particular emphasis is given to ways in which the teacher can enhance students' expression of their ideas orally, in writing and in the course of peer discussion. According to the Standards much of the teacher's discourse should focus on pursuing ideas raised by students and expanding upon them in formal mathematical terms. Standard 3 expands upon the ways in which students can more actively participate in classroom discourse. Students are expected to initiate problems and questions, to raise conjectures, to offer both examples and counterexamples, to convince themselves and others of the validity of their viewpoints and to use mathematical forms of argumentation. Standard 4 states that the discourse forms specified in the preceding standards can be realized in a variety of instructional formats and through various media including computers, stories, concrete models, writing and oral dramatizations. Students should be offered choices in addition to teacher-directed formats.

Although the other standards deal less directly with communication, effective discourse provides the environment in which these standards can be accomplished. Children are likely to find tasks more worth doing (Standard 1) when they are allowed to communicate their own approach to the tasks and when mathematics enhances their capacity to communicate about topics that interest them. Standard 6, which deals with assessing student progress, also depends upon effective communication. This standard specifies that the teacher should monitor ongoing student learning as the basis for planning. "Observing and listening to students during class can help teachers, on the spot, tailor their questions or tasks to provoke and extend students' thinking and understanding" (National Council of Teachers of Mathematics, 1991, p. 63). The standards also specify that assessment should go beyond paper and pencil methods to include monitoring student discussions, journal writing, and individual interviews. Standard 5 specifies parameters of the classroom environment which facilitate the various forms of communication outlined in the other standards.

Although the NCTM standards provide examples of classroom scenarios to demonstrate how the standards might look in practice, the Communication Framework proposed in this paper provides a systematic way of examining the communication skills required for different aspects of mathematical thinking and learning with reference to instructional techniques that have been used with linguistically and culturally different students. Thus, the more general communication goals can be linked to specific instructional arrangements which suit students with varying needs. Figure 8.2 shows the three major forms of mathematical communication.

Communication About Mathematics entails the need for individuals to describe problem solving processes and their own thoughts about these processes. Since the standards now indicate that much of the work which has been done in traditional classrooms as individual seatwork should now be accomplished through social interactions, students need to externalize processes that may not have even been consciously considered when working alone. This process of externalization may in itself contribute to high order reasoning as well as facilitating classroom communication. Communication In Mathematics means using the language and symbols of mathematical conventions. This is what traditionally has been seen as the real content of mathematics instruction. However, placing this kind of knowledge within a communication framework stresses the interconnectedness of mathematical concepts, in contrast to skills based approaches which see learning as mastery of discrete pieces. Communication With Mathematics refers to the uses of mathematics which empower students by enabling them to deal with meaningful problems. Mathematics can be used both as

Figure 8.2 Communication Framework for Mathematics

A. Communicate About Mathematics

1. Reflection on cognitive processes
   - Descriptive
   - Metacognitive
2. Communicate with others about cognition
   - Give point of view
   - Reconcile with others' views

B. Communicate In Mathematics

1. Mathematical Register
   - Special Vocabulary
   - Particular Definitions of Everyday Vocabulary
   - Modified Uses of Everyday Vocabulary
   - Syntax, Phrasing
   - Discourse
2. Representations
   - Physical Manipulatives
   - Symbolic
   - Verbal
   - Diagrams, Graphs
   - Geometric

C. Communicate With Mathematics

1. Problem-Solving Tool
   - Investigations
   - Basis for meaningful action
2. Alternative solutions
   - Interpret arguments using mathematics
   - Utilize mathematical problem solving in conjunction with other forms of analysis

an esoteric way of communicating intended to mystify and as an analytic tool for clarifying complex situations. All three kinds of mathematical communication are needed for developing useful mathematical understanding.

As will be shown, no single instructional arrangement can facilitate all forms of mathematical communication. Large group lessons allow the teacher to convey the information necessary for Communicating In Mathematics but children will have limited opportunity to develop their own skills at communicating their reasoning in this context. Likewise, peer based instruction or cooperative learning are not panaceas for the educational problems besetting many children in mathematics. When the actual content and structure of small group interactions are studied, it is found that a minor part of the student communication is about the content of mathematics or entails mathematical discourse (Wilkinson, Lindow and Chiang, 1985). Just as classroom recitations tend to emphasize drill and practice (Knapp et al., 1991), students replicate this within their small groups in certain forms of cooperative learning. In addition, small group participants are not given equal opportunities to participate, with gender and ethnicity being key dimensions along which participation varies (Cohen, 1984).

The Framework and Instructional Applications

Each of the three major categories of mathematical communication will be examined in detail with examples of instructional programs that have incorporated new forms of communication for language minority or culturally different students. As others have noted (Knapp et al., 1991; McKnight, 1991; Secada, 1991; Zucker, 1991) most research on educational innovation in mathematics has been done with relatively advantaged groups of students while classroom practice and research with less advantaged groups continues to stress mastery of basic skills. However, there are examples of exemplary practice and very recent research studies which show the feasibility of this emphasis upon communication skills and higher order mathematical thinking for students of all cultural, socioeconomic and linguistic backgrounds.

Communicating About Mathematics

Both teachers and students need to learn to talk about mathematics from their own point of view. This entails being able to reflect about one's own cognitive processes, both the steps one takes to solve a problem and the metacognitive considerations which guide the problem solving process. Although arithmetic has traditionally been viewed as the application of standard algorithms to computation, children spontaneously use a variety of strategies for even the simplest addition problems (Siegler, 1987). Even professional mathematicians (or particularly mathematicians!) do not always follow standard algorithms when solving problems, especially unfamiliar problems (Schoenfeld, 1985). Social constructivist theories of learning posit that mathematical knowledge and understanding develop through comparison of varying problem solving methods.

A necessary but even more difficult adjunct of describing one's problem solving processes is recognizing the metacognitive components. Effective problem solving includes setting goals, judging when those goals have been achieved, checking results and incorporating the general self-regulatory skills which enable one to do these things. Since learning when to use a certain procedure is probably more difficult than learning the procedure itself, recognition of metacognitive skills will enhance effective problem solving.

Equally important as recognizing one's own problem solving process is being able to communicate the process to others. In order to do this the learner must take a point of view thereby justifying and explaining what has been done and why. In addition, group work depends upon comparing this to what others have done and acknowledging differences. Within the new vision of mathematics learning presented by the NCTM standards, multiple solution routes are valued and students should be encouraged to present alternatives to the class. Mistakes also have a valued position within the Communication Framework. Certain apparent misconceptions may actually be what Moschkovich (1992) has labeled transitional conceptions, necessary and useful ideas that aid in the construction of the more standard ideas used within mathematics. Mistakes are also an opportunity for developing forms of mathematical argumentation. For this reason class discussion should focus on why ideas are correct, not whether they are correct or incorrect (Lampert, 1990).

For children from certain cultures or other educational traditions this process of externalizing cognitive processes may be more difficult or alien. Michaels and O'Connor (1990) present an example of a Haitian girl who seems unable to explain her reasoning about a balance scale task in the context of a classroom discussion when other children are doing so. The teacher thinks it might be a language problem because the girl's first language is Haitian Creole. However, an individual interview after the class revealed that the girl was perfectly capable of explaining her reasoning in English or Creole. She did not understand that the teacher's question required her to show this reasoning as part of the expected classroom discourse. A similar effect was found during a performance assessment study with Anglo and Latino students (Baxter, Shavelson, Herman, & Brown, in press). Even when matched for achievement test scores and classroom experience, the Latino children whose home language was Spanish were less likely to explain their problem solving processes than Anglo children or Latino children whose home language was English. Despite some training, the Latino students either did not understand what was expected or were less willing to do it for their adult Anglo interviewers. These examples demonstrate that as the content of classroom discourse changes, some students will need the support of changed participant structures to develop the new communicative competence.

A recent classroom based experiment provides more information on what student discourse about cognitive processes looks like when the class norms of communication change with support from changed participant structures (Thornburg and Karp, 1992). This experiment was based on the ideas of cognitive apprenticeship (Collins, Brown, & Newman, 1989) and involved fourteen classrooms, five at the middle school grade levels. Seventy percent of the children in these classrooms were language minority children, predominantly Spanish speaking. The teachers were taught to use a variety of modeling and scaffolding strategies for teaching mathematical word problems with an emphasis upon verbalizing strategies for solving problems in the course of doing them. When the teachers were bilingual, this was done first in the children's first language and second language practice was phased in. The students practiced these skills in peer collaborative groups by taking turns acting as the expert and novice with the expert using some of the same strategies as the teacher. In addition to significantly improving their achievement test scores after one year, the students changed the style of discourse they used. Classroom observations revealed that they gave more elaborate answers and used more mathematical language during discussions with their peers, particularly when teachers had modeled exploratory language use in their own lessons. Two things are particularly notable about these results. The first is that, apparently, regardless of the language of instruction, students first changed the way they talked about mathematics in their first language and eventually over the course of the year used more English although some kinds of talk never shifted to English. The second is that students did not change the way they responded to teacher questions, continuing to answer briefly and unelaboratedly without demonstrating many of the skills they utilized in peer discussions. This may be a result of the instructional arrangement in which the students practiced the new forms of discourse primarily with peers. In this study the children clearly demonstrated new competency as evidenced in peer discussions and tests results, but these competencies need time and support to generalize to a second language or different participant structure.

A different variant on peer based learning has been incorporated by Project SOAR, a summer program for African American junior and senior high school students who are interested in attending Xavier University (Clewell, 1987). Part of this program is based on the pair problem solving methods of Whimbey and Lochhead (1982). One person of each pair acts as the problem solver and thinks aloud while working through a problem. The listener monitors the problem solver to make sure that each step of the process is vocalized and that taught problem solving procedures are followed. This approach to peer problem solving highlights the metacognitive component of problem solving by giving it an explicit role in peer communication. Project SOAR has had notable success with its participants including increased test scores showing improved analytical thinking skills as well as improved college completion rates in the sciences when compared to non-participants.

Teachers probably need to use a variety of strategies to enable children to build their communication skills about cognitive problem solving. Pairing children with the same first language may be preferable at the beginning as shown in the Thornburg and Karp study (1992). Richards (1991) has suggested the use of the Itakura method (Inagaki, 1981) which facilitates this process in large group discussion. Children are given several different positions on an issue and need to defend their adherence to one position over another. While all children need to choose a position, not all children need to publicly defend it. This way children with less assurance can participate without being put on the spot.

Since many programs emphasize communication among peers in discussions about problem solving, teachers may want to devise strategies for increasing teacher-student communication. Peyton (1990) has suggested methods of enabling language minority students to write dialogue journals to their teachers about school. This practice can be extended to mathematics as reported by Clarke, Stephens and Waywood (in press) for two different projects. In Project Impact students wrote to their mathematics teachers every two weeks to answer questions such as "what was the best thing to happen in math?" The project began with seventh grade students and has been extended down to fourth grade students. A number of instructional changes occurred as teachers learned about the student perceptions of their lessons. In the Vaucluse College Study, Clarke, Stephens, and Waywood (in press), observed female students at a private secondary school which served several distinct ethnic groups. These students wrote in a journal after every math class. Over time the students' views of math began to change from a very descriptive form to a more analytical look at mathematical meaning.

Communicating In Mathematics

There are characteristic words, grammatical structures and ways of talking within the mathematics community which constitute what Halliday (1978) called the mathematical register. Some of the vocabulary is unique to mathematics and clearly recognizable as such, words like coefficient, polynomial and hypotenuse. As shown in Figure 8.2, this constitutes the Special Vocabulary of mathematics. Words, such as square, power and set, which sound very much like everyday English but have a specifically defined meaning in mathematics (Spanos and Crandall, 1990) are referred to as Particular Definitions of Everyday Vocabulary. For the second language user these words may be particularly difficult because the differences between everyday usage and mathematical usage are not always apparent (Cuevas, Mann, & McClung, 1986). Everyday words are also used in mathematics with meanings akin to everyday usage but with more precise or restricted meanings, and are referred to as Modified Uses of Everyday Vocabulary in the Framework. These words also present difficulties because it is not easy to provide precise definitions, and their usage seems to be more consensual than many other words. Moschkovich (1992) gives the example of students attempting to use the word steeper in the context of describing lines on a graph. Although the students had been provided with a working definition of the word steeper at the beginning of a problem solving session, each pair of students had to negotiate its actual usage before being able to use it productively in further conversation.

Mathematics also has some syntactic structures which map important conceptual domains. For instance, Hargis and Knight (1977) note that mathematics has many comparative structures such as "more than/less than" and "as much as" because mathematics is the study of relationships. Word problems present difficulty to all students as well as language minority students because they have unique underlying schema that require mathematical skills beyond the computation involved and reading skills distinct from reading in other areas (De Corte and Verschaffel, 1985; Mayer, 1985).

All of the attributes of mathematical register mentioned above are embedded within the larger context of mathematical Discourse. While mathematical discourse is less clearly defined than other aspects of the mathematical register, Schoenfeld likens it to "sense-making through the dialectic of conjecture and argumentation" (1992, p. 363). Mathematical discourse is distinguished from regular discussions (Pimm, 1987) and from "school mathematics" (Thompson, 1985) as typically found in classrooms. While traditional school mathematics emphasizes correct answers and appeal to authority (e.g. textbook, teacher) for judging correctness, mathematical discourse focuses on the ways in which solutions are reached.

Helping children to deal with the mathematical register entails a number of instructional strategies. More care can be paid to specifying the mathematical meaning of terms as they appear in lessons, particularly those words which have multiple meanings. For the language minority child or child who speaks a nonstandard form of English, this at times may simply consist of translating specific terms from the home language into mathematical terms in standard English (Brenner, 1991; Cuevas, 1983). However, an emphasis on the semantic aspects of the mathematical register in the context of word problems may not be enough to help children gain competency in the mathematics register (Cuevas, Mann, & McClung, 1986) since issues of syntax and discourse are not addressed with this approach.

Word problems are expected to have a smaller part in the mathematics curriculum of the future (National Council of Teachers of Mathematics, 1989) because emphasis will be placed upon more complex problem solving. But word problems can be used to develop skills in the mathematical register through providing children with a starting point for discussing situations in which mathematics can be used. Lo, Wheatley, and Smith (1991) give some interesting examples of how a simple word problem about selling a plant evolved into a discussion of the possible different meanings of the problem depending upon the larger situation it was meant to represent. Cohen and Stover (1981) have shown that children can rewrite word problems to make them easier to solve through strategies such as simplifying the wording and adding diagrams. This procedure could be extended to have language minority and first language children work together to rewrite problems, thereby enhancing skills in the mathematical register. Children can also learn to write word problems or to write stories in which mathematics can be applied. My own experience doing this with Native Hawaiian children resulted in word problems which were more complex than any they would have encountered in their textbooks.

Richards (1991) reports that language minority children with a similar experience in writing problems but with no textbook experience at all scored at a mastery level on the section of a standardized test covering word problems. In contrast, none of their peers in a control class scored at this level.

Although the research literature does not at present offer any examples of mathematics classes for culturally different or language minority children which are taught exclusively as communities of practice with extensive mathematical discourse, Lampert's (1990) description of her own teaching practices and other examples listed in Schoenfeld (1992) provide examples of what this might look like.

The second major area of Communication In Mathematics is that of Representation, the various ways in which problems and solutions can be expressed in what would be considered mathematical form. Although school mathematics often treats the components of mathematics as discrete pieces and has reified this by separately teaching arithmetic, geometry, and algebra, mathematical knowledge in fact is a larger system of knowledge with multiple connections among the components. The various representation forms listed in Figure 8.2 are interconnected, and conceptual understanding in mathematics entails comprehension of the structures that tie together the different representations. Effective communication in mathematics thus depends upon effective translation between these various 'dialects' of mathematical language. Some of the most common forms of mathematical representation are physical manipulatives, symbolic representations, verbal statements, diagrams, graphs and geometric representations. Manipulatives may not seem like a dialect of mathematics but in fact some of the most common materials such as Diene's blocks and attribute blocks were designed to represent the structure of mathematics which underlies elementary arithmetic (Resnick & Ford, 1981).

Even as the use of a broader range of representations becomes accepted as good educational practice for promoting conceptual development in mathematics, the evidence mounts that students have difficulty in seeing the connections between the representations used. The use of base ten blocks to represent place value (Resnick & Omanson, 1986) and pattern blocks to represent fractions (Davis & Maher, 1990) do not necessarily improve computation or even connect to algorithms in many elementary students' minds. At the secondary level students who have successfully completed algebra courses may still fail to see the connections between the components of a linear equation and the graph which conveys the same information (Moschkovich, 1992; Schoenfeld, Smith &

Arcavi, in press). At times this problem may be exacerbated by classrooms that function along social constructivist lines with much peer discussion. As student-constructed procedures become more validated, it can be hard to insert the conventions of mathematics into the learning process. Resnick, Bill, Lesgold and Leer (1991) suggest one way of linking students' informal representations to formal ones. After small group discussions, the groups report back to the class at large. The teacher records the informal and sometimes idiosyncratic results in formal notation. As a result the formal notation becomes the lingua franca of the class as a whole.

The Algebra Project developed by Moses (Moses et al., 1989) has a standard topic development sequence which links both the mathematical register and various representations that might be utilized by students. This sequence was developed to help students, particularly minority students, make the transition from arithmetic to algebra with the goal of entering college preparatory mathematics at the beginning of high school. The sequence begins with physical events which embody a mathematical idea, for instance using the subway lines to represent number lines. After riding the subway, students then make a pictorial or other representation of this experience. The next step is to describe the mathematical concept in Intuitive Language, i.e., the student's own words. The students then learn to translate these to Regimented English which seems to correspond to the mathematical register. The final step is learning the symbolic representation. The program is now in use with students between sixth and eighth grades and has succeeded in placing many students into more advanced high school classes.

Communicating With Mathematics

While most students seem to acknowledge the importance of mathematics for understanding the world and for many kinds of jobs (National Center for Education Statistics, 1991), this does not necessarily mean that students find their classroom experiences in mathematics meaningful (Mitchell, 1992). A belief in the utility of mathematics is related to higher test achievement and many students claim that they are taking mathematics because it is preparation for attaining future goals such as attending college (Schoenfeld, 1989). But this future oriented view of the utility of mathematics may not be enough to sustain many students through years of a relatively difficult subject. The achievement of all students may be enhanced through more meaningful mathematical experiences beginning in the elementary school years. The final section of the Communication Framework looks at ways that students of the middle school years can communicate about aspects of their immediate world using mathematics.

A number of mathematics programs have incorporated exercises in which students have some opportunities to use mathematics as a tool. A typical example would be to have a classroom lesson which combines measurement and statistics by having students measure the height of each student in the class and then find out the mean, mode and median of the measurements. Similar classroom activities with a higher communication component enable students to investigate a topic of intrinsic interest using mathematics as the tool. In these investigations, the goal is to learn about some phenomenon rather than to practice arithmetic skills. Although Heath's (1983) work focused primarily on literacy, some of her examples show how children can do investigations of their communities which reveal differences between school and community usage of mathematics. One consumer mathematics class examined monetary transactions in a local store and then used these as the basis for writing word problems. The class extended their project to look at miscommunications during financial transactions and kept track of these through journals. Heath claims that such investigations enable children to make sense of the differences between their home and school lives and also familiarize the teachers with the community of the students.

The Finding Out/Descubrimiento integrated science and mathematics program for children in grades 2–5 is based on the principle that children of any cultural group are naturally interested in understanding the physical world (DeAvila, Duncan, & Navarette, 1987). Learning is enhanced when school provides children with the skills that enable them to explore and understand the world because they gain a sense of mastery over their environment. This program is designed for children with different levels of language and literacy skills as well as science and mathematics background. The hands-on activities provide several instances of each scientific and mathematical concept so students have multiple exposure to them and an opportunity to keep developing the depth of their understanding. Materials are in both Spanish and English and the tasks have pictograph directions as well. The students receive training in social skills to facilitate the cooperative group work required on each activity. Children who participate in the program acquire enhanced language and problem solving skills as well as improved achievement test scores.

While the examples given above enable students to use mathematics to learn more about the world, Mellin-Olsen (1987) argues that for mathematics to be meaningful to young people who are currently disenfranchised by the school system, it must become the basis for action in the world. He gives examples of how activities that young people do in the world such as sewing symmetrical patterns or constructing club houses can become part of the classroom lesson. Mathematics can also be used to address conditions of life outside of school such as the wage structure of local employers or potentially dangerous traffic patterns around the school. The analysis of everyday situations then becomes the data supporting a report to the city council asking for more traffic lights or the basis of a request for more youth services at local clubs. Mellin-Olsen stresses how the end product of the mathematical activities should be more than a poster or report that stays within the classroom.

The examples given above about the utility of mathematics for communication about the world need to be supplemented with a perspective which makes people discriminating users and consumers of mathematics. Koblitz (1984) and Schoenfeld (1991) give multiple examples of ways in which mathematics has been used to make a point through mystification or misdirection. Poor use of statistics, misleading graphs, and multiple equations which have no mathematical validity are all too common in both the popular and academic media. The analysis of such examples from the daily newspaper can supplement other kinds of classroom activities and provide the basis for very directed classroom discussions. The students can learn to use valid mathematical analysis to interpret the arguments put forward by others through critiquing and re-analyzing faulty arguments.

Equally important for student empowerment is recognition that a mathematical analysis alone does not always provide the best solution to a problem. For instance it is possible to do a mathematical analysis of how many items people should be allowed to buy in the express line at the supermarket. This would entail quantifying the relevant variables and then gathering data on how long it takes the cashier to ring up different numbers of items, whether the total number of items should fit in one bag and how long it takes people to pay for the items. However, the real utility of the express line might be to give people the impression that they are preceded by people with only a few items and this sense of 'few' depends upon local definitions of relative quantity. There are also cultural constraints about which problems are best addressed mathematically. Many Native American children are familiar with traditional games of chance (Cheek, 1984) and these games provide a good context for analyzing concepts of probability. For children in communities with certain religious traditions, games of chance are considered gambling and are not a good context for analyzing probability.

One very recent mathematics curriculum explicitly incorporates other forms of reasoning into student problem solving activities. The Mathematics of the Environment curriculum (Mitchell, Baab, Campbell-LaVoie, & Prion, 1992) asks students to find solutions to environmental problems of specific nations using real data about human population, food and energy. Students are taught to use logic chains to identify problems and evaluate potential solutions to those problems. Within this context there are clearly multiple possible solutions to a problem such as an imbalance between population growth and food production. One mathematically satisfying solution to this problem (satisfying in the sense of being supported by clear data and a parsimonious solution process) is to reduce population growth. However, the cultural norms of a country may preclude this solution and a more difficult solution involving increased food production or importing of food must be assessed.

Contexts for Improving Mathematics Communication

The Communication Framework for Mathematics provides a set of ideas for improving mathematics learning through increased interactional opportunities in the classroom. To move from traditional instructional methods to a communications rich format takes time and effort on the part of both teachers and students. There are concomitant changes in other aspects of mathematics education that can facilitate the success of instructional innovations aimed at increasing mathematical discourse. The final section of this chapter addresses contextual issues in the areas of curriculum, other instructional concerns and institutional support.

Curricular Contexts

Implicit within the Communication Framework for Mathematics is a new conception of the mathematics curriculum. In order for students to communicate across different forms of mathematical representations and about more meaningful situations, students will need a wider range of mathematical tools at their disposal. Traditionally the presecondary mathematics curriculum has focused on computational skills, and this continues to be the case for so-called disadvantaged students in particular (Knapp et al., 1991). How-

Figure 8.3 NCTM Curriculum Standards
Grades 5 to 8

Processes

- Problem Solving
- Communication
- Reasoning
- Connecting topics and concepts

Content

- Number/Operations/Computation
- Patterns and functions
- Algebra
- Statistics
- Probability
- Geometry
- Measurement

Source: National Council of Teachers of Mathematics, *Curriculum and Evaluation Standards for School Mathematics (1989)*. Adapted from pp. 65–119.

ever, the research base for mathematics education indicates that the traditional emphasis on mastery of basic skills prior to teaching conceptual or higher level thinking in mathematics has been ineffective and insufficient for American students (Romberg & Carpenter, 1986; Schoenfeld, 1992). The mathematics reform movement as embodied in such documents as the National Council of Teachers of Mathematics Curriculum Standards (1989) and the California State Framework for Mathematics (California State Department of Education, 1992) emphasizes that *all* students should have access to a full range of mathematical topics which include an emphasis on more advanced mathematical processes including problem solving, reasoning, estimation and communication. Figure 8.3 lists the processes and topic areas recommended for middle grade students. Mathematical achievement for diverse student populations depends upon access to a higher level mathematics curriculum, one which is now denied to many students from culturally and linguistically different backgrounds (Oakes, 1990).

Instructional Contexts

The communication framework for mathematics assumes that children from any given culture can become effective communicators in a variety of different mathematical contexts. However, the educational community does not yet know how to make this happen equally well for all children. There are three unresolved issues that need to be considered when observing or designing exemplary mathematics programs for diverse student populations: matching instructional group arrangements to student needs, the language of instruction, and the role of technology.

The many examples given about educational projects that have incorporated different aspects of mathematical communication should have made clear that there are many different instructional arrangements in which mathematical communication can be fostered—pair problem solving, cooperative groups, large group discussion, individual student journals and regular written assignments. Teachers face the issue of deciding when to use which kind of structure for which students. The success of recently introduced small group instructional techniques has at times been taken to imply that many children can learn only in such contexts, and post hoc cultural explanations have been developed to support this point of view. Several recent articles on Native American groups, the Navajo (McCarty, Wallace, Lynch, & Benally, 1991) and the Yup'ik Eskimo (Lipka, 1991), provide examples of successful large group lessons. In both cases the authors emphasize that whole group instruction was facilitated because the teachers share certain social values with their students and because the material was culturally relevant to the students. The examples given by these authors are important, although they are not about mathematics instruction, because there are times when the class as a whole is the best forum for developing mathematical ideas. As Magidson (1992) points out, it is not possible for a teacher in a normal sized class to effectively monitor every student's (or group of students') construction of mathematical knowledge. In addition, the diversity of ideas that seems essential to social constructivist theories of learning is more apt to be obvious when the class as a whole pools its knowledge. More study of the participant structures of large group lessons is needed in order to find culturally appropriate ways of engaging students in whole class instruction in ways that avoid the pitfalls of the traditional recitation.

The emphasis given here to communication in mathematics classrooms raises the issue of what language should be used for mathematics learning for students in the United States who have limited proficiency in English. A recent literature review (Secada, 1992) summarizes the extant literature as follows: "Hence the research on bilingual education indicates that LEP students are likely to be better off receiving instruction in their native language. But we are only beginning to learn about the processes by which the use of the native language might translate into better mathematics achievement" (page 644). The Communication Framework for Mathematics puts the emphasis upon styles of discourse as the essence of communication rather than language more narrowly construed as vocabulary and syntax. Certainly, the forms of communication described in the Framework can be done in any language and practice in discourse styles probably transfers across languages. At the same time it should be recognized that the forms of discourse described here may be particularly alien for a child entering the American school system from another school system. American children are likely to have experience with inquiry methods of learning, group work and the expression of individual opinions in other subjects such as social studies (Stodolsky, Salk, & Glaessner, 1991) or science. When given a choice, many students seem to prefer practicing the new discourse styles in their native language (Thornburg and Karp, 1992) before trying them in a second language.

Many claims have been made for how technology can enhance communication in the mathematics classroom. For instance the video-based series *The Adventures of Jasper Woodbury* is said to promote complex problem solving skills in a context where the effects of different reading skill levels of students and prior experiences are mitigated through the visual presentation of engaging stories (The Cognition and Technology Group, 1990). The computer has also been seen as a tool which promotes active discussion in mathematics classrooms in ways that differ from pencil and paper tasks (Hoyles, Sutherland, & Healy, 1991). A number of reasons are given for how the computer does this. It may facilitate student talk by providing an external focus for conversation. Or perhaps it forces more collaboration through the need to make joint decisions before taking a unitary action on the computer.

Unfortunately, to date there is little information on how innovative technology can be used with culturally and linguistically diverse student populations. DeVillar and Faltis (1991) provide a critique of the claims made for innovative instruction with technology. They point out that the increased talk reported by many authors has not been adequately described in terms of either its content or distribution among different participants in the classroom. DeVillar and Faltis claim that social integration and cooperation are necessary within the heterogeneous classroom before computers have the desired benefits for communication and content learning. González-Edfelt's (1990) research provides some empirical evidence about how the computer supports communication goals. She found that while using problem solving software, student talk was indeed extensive and often in forms, such as explanations, which are known to promote learning in mathematics. Spanish-speaking students with limited proficiency in English were most likely to participate verbally when they were matched with partners who also spoke Spanish and they could use Spanish at least part of the time. However, pairs constituted of an English monolingual student and a student with very limited proficiency in English resulted in very passive behavior on the part of the latter students. These students apparently benefitted little from having the computer as a tool in this context.

At present, expensive technology is not equally available to all students and may be creating what some authors have called "a virtual epidemic of inequality" (Cole, Griffin, & The Laboratory for Comparative Human Cognition, 1987, p. 54). In addition, the uses made of computers seem to differ by gender, class and ethnicity, with more advantaged groups using computers for purposes that more closely match the goals implicit in the Communication Framework for Mathematics. Even within the research literature, the emphasis continues to be on how computers can remediate basic skills deficits for such disparate groups as Chapter 1 students, bilingual students and special education students (Swan, Guerrero, Mitrani, & Schoener, 1990).

Institutional Contexts

Most of the examples given here about how communication can be fostered in mathematics have been focused on classroom level dynamics. However, the environment of the school or school district may be critically important for the long term success of changes in instructional methods. Heath's (1983) work stands out as exemplary in documenting how classrooms can be altered to fit the cultures of the participants while enhancing communication across cultures. Heath also bluntly reports on how the innovations developed by individual teachers disappeared as the school district instituted more criterion referenced testing and more of a top down emphasis on skills based teaching.

The Algebra Project (Moses et al., 1989) in contrast provides an example of how an entire school cooperated to support the students' preparation for high school algebra. The curricular changes were initiated in eighth grade classrooms but eventually the new curricular emphasis was extended to all grade levels, sixth through eighth, for students of all achievement levels. Thus, expectations were raised for all students in the schools. The school community was expanded to include parents as an integral part of the changes. A study of high schools that are particularly effective with Latino language-minority students (Lucas, Henze, & Donato, 1990) presents a similar picture of the comprehensive effort that facilitates mathematics as well as other academic achievement. Throughout the curriculum more emphasis was given to the students' cultures and the Spanish language. Even many Anglo teachers had learned Spanish and Spanish was allowed in most school contexts. Expectations for mathematics achievement were raised by providing advanced mathematics courses in Spanish as well as by reducing the number of remedial mathematics courses. Teachers had become familiar with mathematics instruction in Mexico and were able to help students learn new material using the skills they had been taught in Mexican schools. As in the Algebra Project, parents were involved in the school changes.

Summary and Conclusions

The Communication Framework for Mathematics has been presented as a tool for facilitating analysis of communication in mathematics classrooms. In this chapter it has been used to examine how instructional innovations advocated by the mathematics reform movement can meet the needs of linguistically and culturally different students when learning mathematics. Although the research base is still somewhat limited, an effort was made to demonstrate that a variety of teaching-learning arrangements can increase student involvement with corresponding gains in achievement. Several aspects of the suggested reforms hold particular promise for linguistically and culturally different students. A much wider range of instructional methods are favored including peer collaboration, open-ended problem solving, and open-ended large group discussion, which will enable teachers to accommodate the participant structures that are comfortable for more students. The constructivist model of the learner is acknowledged and gives rise to recommendations for more active learning modes which will engage a wider range of students. The recognition that students need to connect new knowledge to prior knowledge will encourage teachers to use meaningful problems, including those based on real situations from the lives of students.

At the same time, many of the communication skills required by the mathematics reform movement will pose a challenge, or perhaps even a barrier to many students, particularly linguistic minorities. A wider range of discourse styles will be expected of students and it is not clear whether bilingual programs or ESL teaching methods will prepare students for all of them. Writing will be a much larger part of the mathematics curriculum, once again providing a hurdle to second language speakers, as well as many native speakers of English. To some degree traditional mathematics instruction fits prescriptions of what has come to be called sheltered English instruction (Snow, 1990): predictable lesson structures, extensive review, language-independent presentation of materials (e.g. symbolic computation), explicit teacher modeling and frequent comprehension checks. These are less likely to be features of mathematics instruction in innovative classrooms. Thus teachers and students alike will need to come to grips with a high level of language demand, a task which many mathematics teachers, as well as students, are ill-equipped to do.

As the mathematics reform movement gains momentum, researchers and practitioners alike need to consciously consider the implications of educational innovations for all students. Since some of the stated goals of the reform movement are to incorporate currently under-represented groups in more advanced mathematics training and to raise the general level of mathematical literacy in American society, the needs of students of linguistically and culturally diverse populations must be incorporated into all aspects of educational change from planning to implementation to assessment.

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Article 4

Education of Linguistically and Culturally Diverse Students: Effective Instructional Practices

ARTICLE 4: Education of Linguistically and Culturally Diverse Students: Effective Instructional Practices

Garcia, E. (1991). Education of linguistically and culturally diverse students: Effective instructional practices. *Educational Practice Report #1*. Santa Cruz, CA: University of California, National Center for Research on Cultural Diversity and Second Language Learning.

Garcia presents summaries and analysis of some common attributes that recent descriptive research has documented in classrooms where linguistically and culturally diverse students have been particularly successful. Like Brenner, Garcia highlights the importance of effective communication in the classroom and of opportunities for students to work collaboratively in small groups. He describes the prevalence of an integrated approach to curriculum. Garcia also discusses studies of language of instruction which show that students in these kinds of classrooms made the transition from their own language to English without pressure from teachers to do so. Garcia emphasizes that instruction in these classrooms respects and builds on the students' home language and culture.

Questions

- Garcia offers a general conclusion that "Instructional strategies that serve (linguistically and culturally diverse) students well acknowledge, respect, and build upon the language and culture of the home." What might Garcia mean by this? What do you do in your classroom that you feel builds on and acknowledges the home language and culture of your students? In what ways might you build connections between students' experience and science and mathematics ideas and practices?

- In what situations (in school/ out of school, different places in school, during group work) do your students speak in their home language(s)? Do you see differences in participation when students use their native language or English? Do students translate for each other? Consider a bilingual student in your class who is struggling in math or science. What role does and could native language play for this student? How might you investigate this?

The United States continues in a trend of ethnic and racial population diversification, a fact that is particularly evident among young and school-age children. Moreover, the next generation of ethnic and racial minority children continues to be placed "at risk" in today's social institutions. State and national reports regarding the academic achievement, economic condition, and future employment prospects of our culturally and linguistically diverse children indicate significant academic underachievement, high poverty rates, high teen pregnancy rates, and low-skill, low-paying employment opportunities. The future lies in understanding how a diverse population, in such a situation of risk and vulnerability, can achieve social, educational, and employment competence. Our vulnerable populations must succeed. In them reside the new ideas, energy, and resources for our society's future.

Linguistically and culturally diverse children in the United States have, in fact, always found themselves in a vulnerable situation. "Linguistically and culturally diverse" is a relatively new educational term, however, which expresses little appreciation for the diversity among the many populations it encompasses. Educational leaders, such as former Secretary of Education Lauro Cavazos, have concluded that populations identified as linguistically and culturally diverse have been perceived by the majority society as linguistically, cognitively, socially, and educationally vulnerable because of their non-mainstream culture and their lack of English proficiency at the critical age for schooling (Cavazos, 1990). This perception has led to a variety of social and educational programs aimed at ridding this population of those characteristics that put them at risk (Barona & Garcia, 1990).

In this paper, we will look specifically at linguistically and culturally diverse students who enter the formal education process from homes and communities in which English is not the primary language of communication. These students display a portrait of unrealized academic success. Table 1 (on pages 10-11) summarizes present statistical data relevant to the largest population in this broad category: Hispanic students. The table attempts to define this population more clearly by focusing on general demographic indicators as well as on specific educational characteristics and specific social indices that mark this population as particularly vulnerable in U.S. institutions. With regard to the educational situation, the picture painted by these statistics is deplorable, including a 40% non-graduation rate, a 35% grade retention rate, a 2-4 grade-level achievement gap, and a school segregation circumstance of 70%, up from 56% in the 1950's. Figure 1 (on page 9) presents more relevant California schooling information. These data delineate quite dramatically the anticipated rise in the number of culturally diverse school-age students over the next four decades. In 1986, less than 50% of California's school-age population was non-Anglo. That percentage is expected to increase to 60% by the year 2000, and to a high of 70% by 2030.

Recent research has redefined the nature of our linguistically and culturally diverse students' educational vulnerability. It has destroyed stereotypes and myths and laid a foundation upon which to reconceptualize present educational practices and launch new initiatives. This foundation recognizes both the homogeneity and the heterogeneity within and among linguistically and culturally diverse populations. No one set of descriptions or prescriptions will suffice. However, it is useful to give particular attention to features shared by members of these populations, including their bilingual/bicultural character and certain aspects of their instructional circumstances. The following discussion provides a brief overview of recent research addressing effective instruction for these students, with particular emphasis on instructional strategies and staffing characteristics.

Effective Instructional Practices

The present synopsis and analysis rest on the foundations established by recent research documenting educationally effective practices used with linguistically and culturally diverse students in selected sites throughout the United States: Carpenteria, CA (Cummins, 1986); San Diego, CA (Carter & Chatfield, 1986); Phoenix, AZ (Garcia, 1988; Moll, 1988); and the San Francisco Bay Area (Lucas, Henze, & Donato, 1990; Pease-Alvarez, García, & Espinosa, in press). These descriptive studies identified specific schools and classrooms whose Latino, American Indian, Asian, and Southeast Asian language minority students were particularly successful academically, with academic achievement measured at or above the national norms. It is important to note that much of these data have concentrated on Latino students. The case study approach adopted by these studies included examination of pre-school, elementary, and high school classrooms. Teachers, principals, parents, and students were interviewed and specific classroom observations were conducted to assess the dynamics of the instructional process. The results of these studies provide important insights with regard to general instructional organization, literacy development, academic achievement, and the perspectives of students, teachers, administrators, and parents.

High Levels of Communication

A large number of common attributes were identified in the instructional organization of the classrooms studied. Functional communication between teacher and students and among fellow students was emphasized more than might be expected in a regular classroom. Teachers were constantly checking with students to verify the clarity of assignments and the students' roles in those assignments. Classrooms were characterized by a high, sometimes even noisy, level of communication emphasizing student collaboration on small group projects organized around "learning centers." This organization minimized individualized work tasks, such as worksheet exercises, and provided a very informal family-like social setting in which the teacher either worked with a small group of students— never larger than eight and as small as one—or traveled about the room assisting individuals or small groups of students as they worked on their projects. Large group instruction was rare, usually confined to start-up activities in the morning.

Integrated and Thematic Curriculum

Significantly, the instruction of basic skills and academic content was consistently organized around thematic units. In the majority of classrooms studied, the students actually selected the themes in consultation with the teacher, either through direct voting or through some related negotiation process. The teacher's responsibility was to insure that the instruction revolving around the chosen themes covered the school district's content- and skill-related goals and objectives for that grade level. The theme approach allowed teachers to integrate academic content with the development of basic skills. The major thrust in these classrooms was the appropriation of knowledge centered around chosen themes, with the understanding that students would necessarily develop basic skills as a means to appropriate this knowledge. Students became "experts" in thematic domains while also acquiring the requisite academic skills.

In one third grade classroom, the teacher asked students early in the year, "What do you want to learn about?" Besides the usual responses from the students regarding their desire to learn to "read," " do math," "write," etc., one student indicated that he wanted "to learn about the chemicals that my father has that are making my little brother sick"—pesticides. The teacher, with the assistance of the students, determined what the students already knew about pesticides, made a list of questions to which the students hoped to find answers, and developed a set of specific learning goals. Over the next five weeks, the classroom organized reading, writing, research, science, math, and social studies assignments that addressed these learning goals in an integrated fashion. The teacher guided students through a variety of learning activities while making sure that students developed and utilized district-articulated grade-level skills in reading, writing, mathematics, and social studies. Students developed those skills while acquiring knowledge in a challenging and highly relevant domain.

Collaborative Learning

Reported micro-analysis of instructional events in literacy and math, along with analysis of actual literacy products (dialogue journals, learning logs, writing workshop publications, etc.) and math products (learning logs, homework, surveys, etc.), indicated that teachers in Latino language minority classrooms organized instruction in such a way that students were required to interact with each other utilizing collaborative learning techniques. It was during student-student interactions that most higher order cognitive and linguistic discourse was observed (García, 1988). Students asked each other hard questions and challenged each other's answers more readily than they did in interactions with the teacher. Moreover, students were likely to seek assistance from other students and were successful in obtaining it.

Language and Literacy

Another feature noted in the classrooms studied was language of instruction. In classes with Spanish speakers, lower-grade teachers used both Spanish and English, whereas upper grade teachers utilized mostly English. However, students were allowed to use either language.

With regard to the literacy development of Spanish-speaking students, observations revealed the following:

(a) students progressed systematically from writing in the native language in the early grades to writing in English in the later grades;

(b) students' writing in English emerged at or above their grade level of writing in Spanish;

(c) students' writing in English was highly conventional, contained few spelling or grammatical errors, and showed systematic use of invented spelling; and

(d) students made the transition from Spanish to English themselves, without any pressure from the teacher to do so.

Unfortunately, limited research with non-Latino students with regard to this form of micro-analysis is available.

Perceptions

Interviews with classroom teachers, principals, and parents from diverse cultural and linguistic backgrounds revealed an interesting set of perspectives regarding the education of students in the schools studied.

Classroom teachers were highly committed to the educational success of their students; perceived themselves as instructional innovators utilizing new learning theories and instructional philosophies to guide their practice; continued to be involved in professional development activities, including participation in small-group support networks; had a strong, demonstrated commitment to school-home communication (several teachers utilized a weekly parent interaction format); and felt that they had the autonomy to create or change the instruction and curriculum in their classrooms, even if they did not follow the district's guidelines to the letter. These instructors "adopted" their students: They had high academic expectations for all of them ("Everyone will learn to read in my classroom") and they served as advocates for their students. They rejected any suggestion that their students were intellectually or academically disadvantaged.

Principals tended to be well informed and highly articulate about the curriculum and instructional strategies undertaken in their schools. They were also highly supportive of their instructional staff, taking pride in their accomplishments. They reported their support of teacher autonomy, although they were quite aware of the pressure to conform strictly to district policies regarding the standardization of curriculum and the need for academic accountability (testing).

Parents expressed a high level of satisfaction with and appreciation for their children's educational experience in these schools. All indicated or implied that their children's academic success was vital to the children's future economic success. Both Anglo and non-Anglo parents were quite involved in the formal parent support activities of the schools. However, Anglo parents' attitudes were somewhat distrustful of the schools' specific interest in doing what was best for their child. Conversely, non-Anglo parents expressed a high level of trust for the teaching and administrative staff.

Conclusions

The research described above addressed some significant practice questions about effective academic environments for linguistically and culturally diverse students:

(1) *Did native language instruction play a role?*

The schools in these studies considered native language instruction key in the early grades (K-3).

(2) *Was there one best curriculum?*

No common curriculum was identified in these studies. However, a well-trained instructional staff implementing an integrated student-centered curriculum, with literacy pervasive in all aspects of instruction, was consistently observed across grade levels. Basals were utilized sparingly and usually as resource material.

(3) *What instructional strategies were effective?*

Teachers consistently organized instruction so as to insure heterogeneous small-group collaborative academic activities requiring a high degree of student-to-student interaction. Individual instructional activity was limited, as was individual competition as a classroom motivational ingredient.

(4) *Who were the key players in this effective schooling drama?*

School administrators and parents played important roles, but teachers were the key players. They gained the confidence of their peers and supervisors. They worked to organize instruction, create new instructional environments, assess instructional effectiveness, and advocate for their students. They were proud of their students—academically reassuring but consistently demanding. They rejected any notion of academic, linguistic, cultural, or intellectual inferiority in their students.

These features of effective classrooms for linguistically and culturally diverse students contribute, above all, to the establishment of an interactive, student-centered learning context. In other words, effective instructional staff recognize that academic learning has its roots in processes of social interaction. This type of instruction provides abundant and diverse opportunities for speaking, listening, reading, and writing along with native language scaffolding to help guide students through the learning process. A focus on social interaction encourages students to take risks, construct meaning, and seek reinterpretations of knowledge within compatible social contexts. Within this knowledge-driven curriculum, skills are tools for acquiring knowledge, not a fundamental target of teaching events (Tharp & Gallimore, 1988; Garcia, 1988).

Implications

The above set of descriptive data can be perceived of as providing a new set of understandings regarding the effective academic instruction of linguistically and culturally diverse students. The practices identified here as effective have also been affirmed by recent educational intervention research aimed at restructuring education for these students (Rivera & Zehler, 1990). The convergence of findings from this new empirical research, including those described here, generates the following set of specific guides:

- Any curriculum, including one for diverse children, must address all categories of learning goals (cognitive and academic, advanced as well as basic). We should not lower our expectations for these students; they, too, need to be intellectually challenged.

- The more linguistically and culturally diverse the children we teach, the more closely we must relate academic content to the child's own environment and experience.

- The more diverse the children, the more integrated the curriculum should be. That is, multiple content areas (e.g., math, science, social studies) and language learning activities should be centered around a single theme. Children should have opportunities to study a topic in depth, and to apply a variety of skills acquired in home, community, and school contexts.

- The more diverse the children, the greater the need for active rather than passive endeavors, particularly informal social activities such as group projects, in which students are allowed flexibility in their participation with the teacher and other students.

- The more diverse the children, the more important it is to offer them opportunities to apply what they are learning in a meaningful context. Curriculum can be made meaningful in a number of creative ways. Science and math skills can be effectively applied, for example, through hands-on, interactive activities that allow students to explore issues of significance in their lives, such as an investigation of the quality of the local water supply.

In conclusion, information derived from recent research indicates that linguistically and culturally diverse students can be served effectively. These students can achieve academically at levels at or above the national norm. The instructional stategies that serve these students well acknowledge, respect, and build upon the language and culture of the home. Students become important partners with teachers and parents in the teaching/learning enterprise. Teachers play the most critical role in students' academic success. Although much more research is required with the great diverse populations of students served by our schools, we are not without a knowledge base that can make a difference.

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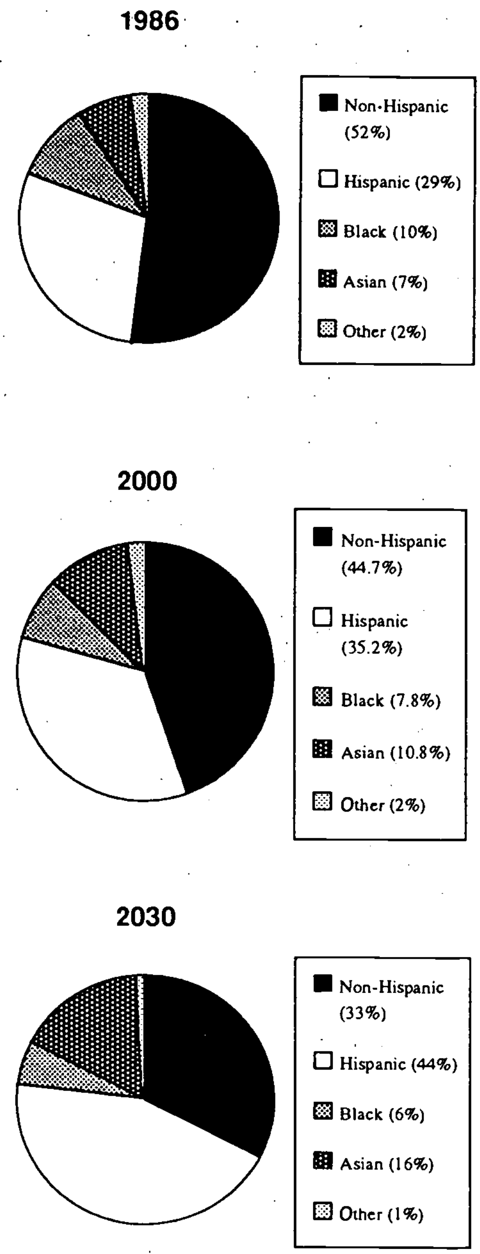
FIGURE 1

CALIFORNIA'S SCHOOL AGE POPULATION BY RACE/ETHNICITY



Source:

Olsen, L. (1988). *Crossing the schoolhouse border: Immigrant students and the California public schools.* San Francisco: California Tomorrow.

TABLE 1

HISPANIC DEMOGRAPHIC SYNTHESIS

I. **General Demographic Character**

A. Of the 18.8 million Hispanics in the continental United States, the following characterizes the population's ethnic diversity:

Country/Area of Origin	*Number*	*Percent*
Mexico	11.8 million	62.8
Puerto Rico	2.3 million	12.2
Central/South America	2.1 million	11.2
Cuba	1.0 million	5.3
Other	1.6 million	8.5

B. 82% of this Hispanic population is found in eight states: California (31%), Texas (20%), New York (11%), Florida (6%), Illinois (4%), Arizona (3%), Colorado (3%), New Mexico (3%).

C. Average age of this population is 25.1 years (compared to 32.6 years for the general United States population).

D. 200,000 Hispanics immigrate legally to the United States yearly, which represents 40% of all legal immigrants. An estimated 200,000 Hispanics immigrate illegally each year.

E. The U.S. Hispanic population grew by 61% from 1970 to 1980 compared to an 11% growth in the general population.

F. 11 million Hispanics report speaking Spanish in the home.

G. 7% of U.S. Hispanics live in metropolitan areas; 50% in central cities.

II. **Education**

A. 40% of Hispanics leave school prior to high school graduation (40% of those leaving do so by grade 10).

B. 35% of Hispanics are held back at least one grade.

C. 47% of Hispanics are over-aged at grade 12.

D. 85% of Hispanic students are in urban school districts.

E. 70% of Hispanic students attend segregated schools (up 56% from 1956).

F. Hispanics score significantly below national norms on academic achievement tests of reading, math, science, social science, and writing at grades 3, 7, and 11, generally averaging 1-2 grade levels below the norm. At grade 11, Hispanics average a grade 8 achievement level on these tests.

III. Indices of Vulnerability

A. Median family income has fluctuated for Hispanics (1972—$18,880; 1982—$16,227; 1986—$19,995), remaining below that of non-Hispanics (1972—$26,261; 1982—$23,907; 1986—$30,321).

B. 29% of Hispanic families live below the poverty line, up from 21% in 1979. (10.2% of Anglo families live below the poverty line.)

C. 905,000 (23%) Hispanic families are maintained by female head-of-household (up from 17% in 1970). 53% of these households live below the poverty line.

D. 50% of Hispanic women are in the labor force.

E. Hispanics are twice as likely as Anglos to be born to unmarried, teen mothers.

F. 56% of Hispanics are functionally illiterate, compared to 46% of Blacks and 16% of Whites.

G. 65% of Hispanics hold unskilled and semiskilled jobs compared to 35% of non-Hispanics.

Sources:

Appleby, A.N.; Langer, J. , & Mullis, I.J.S. (1988). *The nation's report card: NAEP.* Princeton, NJ: Educational Testing Service.

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Article 5

A Vision of Effective Science Education

Article 5

ARTICLE 5: A Vision of Effective Science Education

Center for Science Education. (1997). A vision of effective science education. In J. S. Dietz (Ed.). *Foundations: The Challenge and Promise of K-8 Science Education Reform*. 7-16. Arlington, VA: National Science Foundation.

The **Center for Science Education** chapter outlines how "inquiry teaching," which the authors refer to as modeled on the scientist's method of discovery, "leads students to build their understanding of fundamental scientific ideas through direct experience with materials, by consulting books, other resources, and experts, and through arguments and debate among themselves." The chapter describes classroom examples of inquiry teaching and discusses changes recommended by the 1996 National Science Education Standards published by the National Academy of Science. These changes emphasize guiding students in active and extended scientific inquiry, providing opportunities for scientific discussion and debate among students, and sharing responsibility for learning with students, among others.

Questions

- What elements of "inquiry teaching" do you see exemplified in Ms. Hudicourt-Barnes' or Ms. Strom's work? Why do you think these elements are effective?

- Choose one of the other classrooms (Mrs. Glassboro, Mr. Johnson, Ms. Hernandez) and discuss ways in which you might modify the science unit to be more inquiry-based.

- This article briefly describes the debate about process versus content in science teaching and learning, describing these in their extreme form. What are the extreme forms, and what might constitute a middle ground? What aspects do you value from each extreme, and how do they complement one another, for example, in the cases of effective practice given in the article?

- Is separating process from content a useful way of thinking about approaches to inquiry science? Use data from your own classroom or from other articles in this packet (e.g. Ball, Ballenger, Rosebery et al.) to support your point of view.

A Vision of Effective Science Education

"*Inquiry* is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning and conducting investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating the results," states the National Science Education Standards published in 1996 by the National Academy of Science.

Inquiry, this simple three-syllable word requires a paragraph to explain and a vision to make real. Indeed, the phrase "inquiry-based science education" appears everywhere in the language educators use to redefine the teaching of science. The older approach to science teaching emphasized the end point of scientific investigations embodied in facts and truths of the textbook. Students memorized vocabulary, facts, and formulae. They viewed demonstrations and repeated canned exercises, calling them "laboratory experiments."

Instead, *inquiry teaching* leads students to build their understanding of fundamental scientific ideas through direct experience with materials, by consulting books, other resources, and experts, and through argument and debate among themselves. All this takes place under the leadership of the classroom teacher.

This process of inquiry is modeled on the scientist's method of discovery. It views science as a constructed set of theories and ideas based on the physical world, rather than as a collection of irrefutable, disconnected facts. It focuses on asking questions, considering alternative explanations, and weighing evidence. It includes high expectations for students to acquire factual knowledge, but it expects more from them than the mere storage and retrieval of information.

The Challenge

Inquiry-based teaching is a challenge. Contrary to the claims of some critics, it is not a relinquishing of the teacher's role, nor is it simply *messing about* with materials. It is highly structured teaching—but structured to allow students to behave in a most fundamental human way, to be inquisitive. It requires a teacher who is knowledgeable about scientific content and pedagogy, significant blocks of dedicated classroom time, a system that supports the teacher's own learning, and high-quality materials and curricula. In schools where attempts to implement inquiry-based science education have failed, it is often because one or more of these essential elements are missing. In these instances, the rhetoric and superficial trappings of reform can take the place of real change.

Hands-on science is not necessarily good science, as evidenced in Mrs. Glassboro's"gen1"[1] elementary school classroom:

> Today and for the next several weeks, the children will be studying organisms and their needs. The topic this week is worms. The children have read a book about worms and they are writing stories about their feelings for worms to go with the pictures they have drawn of worms in the school yard. On Friday, Mrs. Glassboro brings in a few worms. The children sit in a circle on the floor, watch the worms, and discuss what they look like and what they are doing. They pass the worms around for all to touch. At the end of the day the worms go back outdoors and the study of worms is complete.

Although one might claim that this teacher is using hands-on methods, many of the important characteristics of inquiry and effective science teaching are absent, rendering the exercise nearly meaningless for the children. The teacher offers the students direct experience with worms only as the capstone of the exercise. No unifying science concepts about living organisms guide the teaching or learning, nor are any generalizations postulated or tested—only topics relating to the specific characteristics of the earthworm are discussed. There is little opportunity for students to formulate and ask questions, to help shape their own learning, or to debate their ideas with each other. Rather than building an understanding of basic concepts about living things, they finish their science unit simply having learned a few facts about worms.

In Mr. Johnson's class, the hands-on unit with worms can also be improved:

> **After recess, the students express an interest in worms they found in the playground. Mr. Johnson provides a box and some soil for the worms in a corner of the room. When the children have activity time they are free to investigate the worms. Some of them pull worms from the box and look at them with a magnifying glass, others try to make them race, still others try to feed them bits of food. The teacher places books about worms nearby. Over the 3 weeks that the worms are in the classroom, Mr. Johnson periodically asks the children to report what they have seen or done with the worms, which he charts on an easel for all to see. Twice he asks that the worms be the subject of his students' daily journals. At the end of 3 weeks, the children release the creatures in the playground, concluding the unit on earthworms.**

Again, too few of the critical components of effective science teaching are present in Mr. Johnson's classroom to consider this a successful inquiry-based learning experience. While the students had an opportunity to explore and investigate the worms—3 weeks is a sufficient block of time—the teacher provided almost no guidance, had no clear set of conceptual goals, and had no coherent plan to make the hands-on unit work.

As is clear from the tale of Mr. Johnson's class, not all student questions, observations, and investigations result in worthwhile learning pursuits. It is up to the teacher to provide structure to the students' inquiry and to support their exploration of only those questions that will yield valuable insights into the scientific concepts under discussion.

In yet another classroom, Ms. Hernandez' second-graders have been working on an interdisciplinary thematic unit on world environments and endangered species. However, sometimes themes can obscure the underlying scientific concepts.

> **After reading a chapter in the textbook, the children were put in groups of four and asked to choose a specific environment to illustrate. Six large paintings now adorn the windows, labeled "tundra," "plains," "woodland," "desert," "rain forest," and "alpine." During the second week of the unit, the teacher selected a few activities on habitats so the students could discuss the concept of completeness and examine their local environment.**

Later, the class turned to endangered species. Each group selected a species as the subject of a research project; the resulting mini-reports and diagrams are posted on the classroom bulletin board. As a finale, the students are making their classroom into a rain forest. A tape plays rain forest noises. Books are strewn about. One group of students cuts large tropical trees out of butcher paper. Another makes long, hanging vines. A third paints life-size, parrot-like birds a brilliant red. The work is done. The children are ready to invite their parents and schoolmates to visit the rain forest.

Ms. Hernandez' classroom exhibits some components of inquiry-based science, but the emphasis and focus are not appropriate for the developmental age of the children. Students of this age find it difficult to deeply understand themes of endangered species and world environments. The intellectual scale of the effort is immense; the global distances tremendous. Likewise, there are countless scientific lessons crammed in among the vines, plants, and animals without a critical focus on a tightly knit set of basic ideas.

Although built on hands-on activities, there is no process of inquiry forming the lesson's base. The children have not had the opportunity to investigate these ideas through direct experience. Their learning stems only from secondary sources. The time spent doing scientific investigations and developing an understanding of habitats and their relationships to organisms—both critical to understanding extinction—is small compared to the time spent reproducing words, pictures, and diagrams from library and other materials. Moreover, although connected in a broad sense, the activities do not interlock in ways that permit the understanding of larger, more profound scientific principles.

The Promise

What does an effective inquiry-based science class look like? Ms. Strom uses a well-designed curriculum guide to teach a unit on habitats. Ms. Hudicourt-Barnes leads her students down the path of a lengthy and fruitful investigation by asking a good question about drinking water. Both examples demonstrate what inquiry-based science education can and should be."gen2"[2]

Ms. Strom's goal for the unit on habitats is to reinforce her third graders' growing knowledge of the basic needs of living things while developing in the students a basic understanding of the relationship between an organism and its habitat. As an initial part of the 6-week unit, students investigated habitats around the school, focusing their attention on a few organisms.

By the fourth week of the unit, they have reviewed the basic needs of living things and have, by beginning with themselves and their own needs, explored the idea of complete and incomplete habitats. Then, in small groups, they looked closely at the needs and habitats of living organisms found within 2-foot-square plots in the area around the school. Through small- and large-group discussions, the recording of observations and data in their science notebooks, trips to the media center for reference books and other resources, and consultations with scientists over the Internet, the children's ideas began to crystallize. They began seeing how organisms are adapted to conditions in their habitat and how those habitats provide the organism with the resources necessary to meet its basic needs.

On this particular day, Ms. Strom begins a component of the unit in which the students will build small terraria to temporarily house insects they have seen outdoors. The terraria will allow the students to study more closely how organisms are adapted to habitats. She begins with a discussion of the project and guides the students into thinking about a number of issues as they plan to construct the temporary homes. As Ms. Strom reviews with the students what they have learned, she is also assessing her students' readiness to pull together the knowledge gained over the past few weeks.

The students then divide into their groups to decide which creatures they will collect and to plan terraria to meet the creatures' needs. Toward the end of class, the groups present their ideas and terrarium designs to each other for class discussion and critique. Ms. Strom takes an active role in this discussion, raising critical questions. Several of the groups revise and refine their plans. Later, they gather the materials and capture the creatures. Over the next four classes the students will observe their creatures closely, both within their temporary homes and in small bug boxes. At the conclusion of the exercise the student teams will present what they have learned, the class will discuss their findings, Ms. Strom will bring conceptual closure to the project, and the creatures will then be released into their natural habitats.

Ms. Strom's classroom demonstrates important characteristics of inquiry-based science teaching. Using a written guide from an established curriculum, she carefully follows the story line so that her students' understanding of the underlying biological concepts builds logically in both scope and sequence. The students' inquiry is supported through secondary sources such as electronic media. Their investigations begin by making connections to their own environment.

She is careful to allow time for the students to make entries in their notebooks and to discuss their work in both small and large groups. This, together with her constant informal interventions with students, allows her to continuously assess the children's state of knowledge and to alter her pacing of the unit accordingly.

Ms. Strom's third-grade class has been able to make logical conclusions about habitats based on their own direct experience in this tightly designed unit. For Ms. Hudicourt-Barnes' older students, inquiry takes on more advanced features, a more open direction, and proves itself to be a matter of taste.

> Ms. Hudicourt-Barnes, teacher of a combined seventh- and eighth-grade bilingual class of Haitian youngsters, watched as her students streamed in from gym class one February day only to race off to a far-away third-floor water fountain. She wondered why no one stopped to drink from the much closer, first-floor fountain. After observing the same behavior several times, she asked a few of the students why. All instantly replied that the water was "better" on the third floor. Ms. Hudicourt-Barnes challenged them to prove that this belief, apparently shared by most of the seventh and eighth grade, was really true; and if true, to explain why.
>
> The students set out to determine if they really preferred the third-floor water by designing a blind taste test of water samples from the first-, second-, and third-floor fountains. They found that two-thirds of them chose the water from the first floor in the blind test, although every one of them had previously claimed to prefer the third-floor's water.

The students did not believe their results. Further discussion revealed that the kids firmly believed that the first-floor fountain was the worst because "all the little kids slobber in it." (The first-floor fountain is near the kindergarten and first-grade classrooms.) Ms. Hudicourt-Barnes was also suspicious of the test results, because she had expected no differences among the three fountains. These suspicions motivated the class to conduct a second taste test with a larger sample of tasters drawn from the other seventh- and eighth-grade classes.

The students decided where, when, and how to run the experiment. They discussed methodological issues: how to collect the water, how to hide the identity of the sources, and, crucially, how many fountains to include in the test. They decided to draw from the same three fountains as before, so they could compare results of the two rounds of tests. They worried about bias in the voting process: what if some students voted more than once? Each student took responsibility for a piece of the experiment. About 40 students from other classes participated. When the data were analyzed, the results were similar to the earlier test: 88 percent of the students thought they preferred water from the third floor, but in the test, 55 percent actually chose the water from the first floor.

Faced with this evidence, the students' suspicion turned to curiosity. Why was the water from the first-floor fountain preferred? How could they determine the cause of the preference? Earlier in the year the class had completed a unit on water and the water cycle. In conjunction with the unit they had worked with the local water resources agency and studied where their water came from and how it was cleaned and monitored. They had the tools and understanding to apply to this new problem, and decided to analyze the school's water along several dimensions, including acidity, salinity, temperature, and bacteria levels.

> They found that all the fountains had unacceptably high levels of bacteria. In fact, the popular third-floor fountain had the highest bacteria count of the lot. They also found that the water on the first floor was 20 degrees cooler than the water on the other floors. Based on these findings, they concluded that temperature was probably a deciding factor in the blind taste-test results. They theorized that the water was cooled naturally as it sat in the city's underground pipes and warmed as it flowed from the basement to the third floor.
>
> Ms. Hudicourt-Barnes was delighted with what had come from the initial taste-test idea. Her students had eagerly used computers to analyze their data and write their reports. She was also pleased by the level and quality of interaction between her bilingual class and the monolingual classes.

Ms. Hudicourt-Barnes has a year-long planned science curriculum, including the study of water. But her plan is flexible enough to allow students to pursue an unplanned inquiry in considerable depth. Her classroom offers the materials and tools needed for investigations. She is willing to share responsibility for learning with her students, thereby encouraging thought and reflection, but she also questions and challenges their work and demands evidence and argument to support their assertions.

The Debate Continues

A vigorous debate is currently under way about the most effective ways to teach science. Two critical areas in this debate are the importance of content versus process and the nature of effective instruction. E. D. Hirsch, author of The Schools We Need, argues that content has taken a back seat to process in progressive education, and that so-called direct instruction is preferable to inquiry-based teaching. In an issue of the American Educator he attacks constructivist reforms and cites research to demonstrate the superiority of direct instruction and the acquisition of factual knowledge.

"The only general principle that seems to emerge from process-outcome research on pedagogy," writes Hirsch, "is that focused and guided instruction is far more effective than naturalistic, discovery, learn at your own pace instruction." He argues the need for students to learn substantial content and not simply the process of science and how to learn. "The conclusion from cognitive research," he states, "shows that there is an unavoidable interdependence between rational and factual knowledge and that teaching a broad range of factual knowledge is essential to effective thinking both within domains and among domains" (Hirsch, 1996).

Hirsch is certainly not wrong, but he and other critics are in danger of setting up a false dichotomy of content versus process. Neither is the answer. Teaching that concentrates solely on one and ignores the other is not helpful to students.

Science teaching embraces a wide range of methods. At one end of the continuum is the classroom in which knowledge is defined by the text and students learn from readings and lectures. Their success depends on understanding the requirements of the teacher and learning terms and formulae. On the other end of the continuum is open exploration of materials with little guidance or structure. Hirsch does not advocate the first extreme; he admits a place for inquiry in science education and the need for students to take some responsibility for their learning. Responsible reformers also dismiss the extremes in favor of the middle ground, suggesting that the current changes in science teaching involve a shifting of emphasis along this continuum. The National Science Education Standards call for more or less emphasis on certain instructional strategies as they advocate this move down the continuum.

The heart of the disagreement is about where the proper balance should be. Those who see a need for more emphasis on content will give students less time for investigation, debate, and argument than those who value these processes and who aim for deeper understanding of fewer topics. The latter will give more time to small-group work, argument, and debate, and less time to textbooks and library research.

The current inquiry-based science reform effort values depth of understanding of basic concepts, learning the process of scientific inquiry, and students' assuming significant responsibility for their own learning. There is a balance of content and process in inquiry-based science, but teachers who hold these values may differ in their methods. The character of each classroom emerges from the decisions of teachers and from the rich diversity of individual children, communities, and school systems.

It is not enough for reform-minded educators to turn to the standards, to the research, or to a particular curriculum for answers. We see today many examples of good inquiry-based science teaching, but also many examples of "hollow inquiry," practice that is called inquiry but has few of its essential characteristics. Educators must first understand their own values and engage in their own inquiry—to develop a deep understanding of their communities' needs and goals for rich, vital science education.

Changing Emphases

The National Science Education Standards envision change throughout the system. The teaching standards encompass the following changes in emphases:

Less Emphasis On	More Emphasis On
Treating all students alike and responding to the group as a whole	Understanding and responding to individual student's interests, strengths, experiences, and needs
Rigidly following curriculum	Selecting and adapting curriculum
Focusing on student acquisition of information	Focusing on student understanding and use of scientific knowledge, ideas, and inquiry processes
Presenting scientific knowledge through lecture, text, and demonstration	Guiding students in active and extended scientific inquiry
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion and debate among students
Testing students for factual information at the end of the unit or chapter	Continuously assessing student understanding
Maintaining responsibility and authority	Sharing responsibility for learning with students
Supporting competition	Supporting a classroom community with cooperation, shared responsibility, and respect
Working alone	Working with other teachers to enhance the science program

References

Hirsch, E.D. (1996). Reality's revenge: Research and ideology. American Educator, Fall: 4-6, 31-46.

National Research Council. (1996). National Science Education Standards. Washington, DC: National Academy Press.

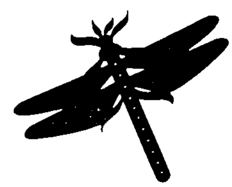
[1] The names used for the three teachers in this section—Mrs. Glassboro, Mr. Johnson, and Ms. Hernandez—are fictitious, made up only for the purpose of illustration.

[2] Portions of this section have been taken, with permission, verbatim from a report titled "Cheche Konnen: Scientific Sense-making in Bilingual Education" in *Hands On* (Spring 1992, Vol. 15, No. 1), a newsletter produced by TERC, an organization that works to improve education. The report was written by Ann Rosebery, Beth Warren, Faith Conant, and Josiane Hudicourt-Barnes about work done under the auspices of the Cheche-Konnen project by Ms. Hudicourt-Barnes' Haitian-Creole bilingual classroom at the Graham and Parks Alternative Public School in Cambridge, MA. The other teacher mentioned in this section—Ms. Strom—is fictitious, made up only for the purpose of illustration.

Articles 6 & 7

Learning with Breadth and Depth

Don't Tell Me How Things Are,
Tell Me How You See Them



ARTICLE 6: Learning with Breadth and Depth

Duckworth, E. (1987). *The Having of Wonderful Ideas*. 70-82. New York: Teachers College Press.

ARTICLE 7: Don't Tell Me How Things Are, Tell Me How You See Them

Nemirovsky, R. (1993). Don't tell me how things are, tell me how you see them. In R. Ruopp, S. Gal, B. Drayton, & M. Pfister (Eds.), *LabNet: Towards a Community of Practice*, 269 - 280. Hillsdale, NJ: Lawrence Erlbaum Associates.

Duckworth presents a view of learning that emphasizes the importance of working through confusion as one means of constructing robust understanding of scientific phenomena. Using descriptions of learning episodes with teachers and students, she makes a case for her belief that one major role for teachers is "to *undo* rapid assumptions of understanding, to slow down closure, in the interests of breadth and depth." She acknowledges that teachers are often pressed and impatient for their students to put forth clear ideas. However, as learners we all need "time for our confusion." Taking time to examine ideas and put them in relation to other ideas forms the basis for "breadth and depth" in our knowledge.

Nemirovsky describes all that an individual brings to a learning situation in terms of a sense of "wonder." He cautions us about the ways in which an "Official Explanation of Things" can suffocate wonder and effectively shut down inquiry. Expanding on the notion of "genuine inquiry," Nemirovsky illustrates from his work interviewing children doing science how genuine inquiry can foster and build on the sense of wonder a learner brings, and lead him/her to explore the "edges" of his/her knowledge.

Questions

- Both authors emphasize aspects of "inquiry learning" that are important to each. What does each author value? What aspects of their points of view do you agree/disagree with? Why?

- What other views of learning as inquiry come to mind or have influenced you?

- Can you think of aspects of an inquiry approach to teaching that you may have used?

- Have you had any personal experiences *learning* through inquiry?

- Have these articles opened up any new perspectives for you on inquiry?

- Is there anything about the classroom talk and activity described in some of the other articles in this packet that you would describe as inquiry? How? (Use examples from the articles to support your point of view.)

- What do you see as the limitations of inquiry in classroom teaching and learning?

Learning with Breadth & Depth

If ideas develop on their own so slowly, what can we do to speed them up? In chapter 3, we pointed out that Piaget referred to this as "the American question." For him the question is not how *fast* you go but how *far* you go. He delighted in the results of a study of kittens carried out by Howard Gruber. Studying his own children, Piaget had concluded that they were about a year old before they realized that an object had its own continuing existence and location even when out of their reach and out of their sight. Gruber found that kittens go through all the same steps that children do, but instead of taking a year, they take six weeks (Gruber et al., 1971). Piaget cheerfully pointed out that you can scarcely say that kittens are better off for having cut almost a year off the time. After all, they don't get much further.

How could it be that going fast does not mean going far? A useful metaphor might be the construction of a tower—all the more appropriate given that Piaget thinks of the development of intelligence as continual construction. Building a tower with one brick on top of another is a pretty speedy business. But the tower will soon reach its limits, compared with one built on a broad base or a deep foundation—which of course takes a longer time to construct.

What is the intellectual equivalent of building in breadth and depth? I think it is a matter of making connections: Breadth could be thought of as the widely different spheres of experience that can be related to one another; depth could be thought of as the many different kinds of connections that can be made among different facets of our experience. I am not sure whether intellectual breadth and depth can be separated from each other, except in talking about them. In this chapter I shall not try to keep them separate, but instead try to show how learning with breadth and depth is a different matter from learning with speed.

Productive Wrong Ideas

If a child spends time exploring all the possibilities of a given notion, it may mean that she holds onto it longer, and moves onto the next stage less quickly; but by the time she does move on, she will have a far better foundation—the idea will serve her far better, will stand up in the face of surprises. Let me develop a hypothetical example to show what I mean, based on the notion of the conservation of area.

Imagine two identical pieces of paper; you cut one in half and rearrange the pieces so the shape is different from the original one, while preserving the same area, as in the example in Figure 6.1. One might think that it would be to anyone's advantage to realize early in life that a change in shape does not affect area; that no matter how a shape is transformed, its area is conserved. But I can imagine a child not managing to settle that question as soon as others because she raises for herself the question of the perimeter. In fact the perimeter *does* change, and thinking about the relationship between those two is complicated work. One child might, then, take longer than another to come to the conclusion that area is conserved, independent of shape, but her understanding will be the better for it. Most children (and adults) who arrive smartly at the notion that area is independent of shape do not think about the perimeter and are likely to become confounded if it is brought up. Having thought about perimeter on her own, she has complicated the job of thinking about area, but once she has straightened it out, her understanding is far deeper than that of someone who has never noticed this difference between area and perimeter.

Exploring ideas can only be to the good, even if it takes time. Wrong ideas, moreover, can only be productive. Any wrong idea that is corrected provides far more depth than if one never had a wrong idea to begin with. You master the idea much more thoroughly if you have

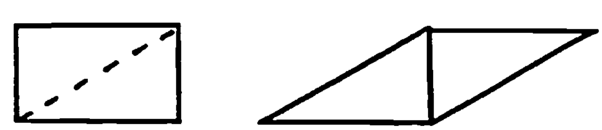


Figure 6.1

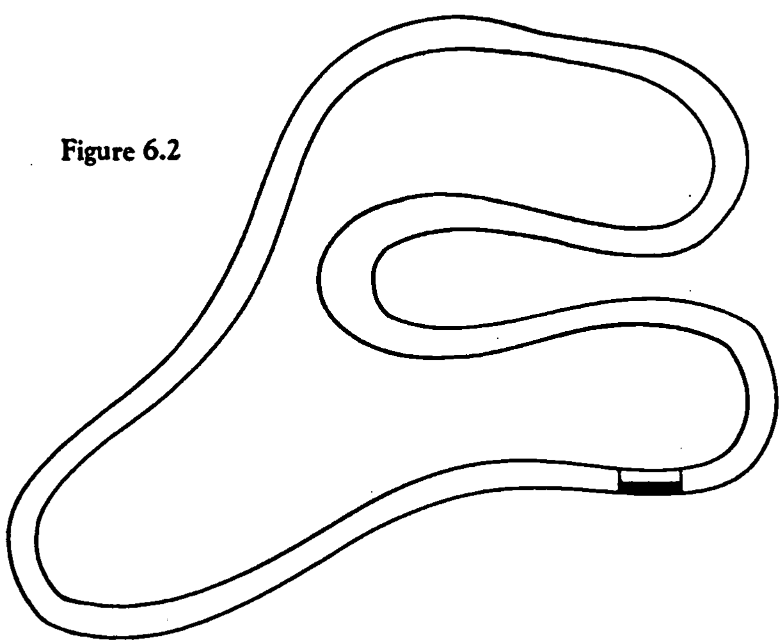
considered alternatives, tried to work it out in areas where it didn't work, and figured out why it was that it didn't work, all of which takes time.

After this hypothetical introduction, here are some examples where making the mistakes and correcting them reveal and give rise to a far better grasp of the phenomenon than there would have been if no mistakes were made at all.

One experiment involves an odd-shaped lake like the one in Figure 6.2 with a road around it, and a bi-colored car on the road, one side black and one side white. Let's say the white side is next to the water to start with; the question is, after the car drives around a corner, or around several corners, which color will be beside the water? Six-year-olds, after one or two mistaken predictions, usually come to be quite sure that it will always be the white. Eight-year-olds, on the other hand, can be very perplexed, and not quite get it straight, no matter how often they see the white side come out next to the water. They keep predicting that *this* time the black side will be next to the water.

Now one might be tempted to think that 6-year-olds know more than 8-year-olds. They, after all, do not make mistakes. But I think it is the greater breadth and depth of the 8-year-olds' insight that leads to their perplexity. Eight-year-olds are often just at the point of organizing space into some interrelated whole: Your left is opposite my right; something that you can see from your point of view may be hidden from my point of view; if a car in front of me is facing right, I see its right side,

Figure 6.2



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and if it turns 180°, I'll see its left side. With all these shifting, relative relationships, what is it about the lake that makes *that* relationship an absolute? No matter how many curves there are in the road, the same side is always next to the water. If a car turns 180°, I thought I would see its other side; well, how is it that the *same* side is next to the water? What is it that stays the same and what is it that changes, after all? The 6-year-old, who has no idea of the systematic changes involved in some spatial relationships, has no difficulty seeing the constant in the lake problem; it is because the 8-year-old is trying to make sense of the lake in a far broader context that the right answer is not so immediate. The dawning organization of something new throws into confusion something that had been simple before. But when, a few months later, the 8- or 9-year-old does start to understand that the same side must always stay next to the lake, his or her understanding is far deeper than that of the 6-year-old; it is set in the context of an understanding of spatial relationships as a whole.

Here is another example, where what appears to be less facility really indicates greater understanding. I was working with two children, who happened to be brother and sister, and they were making all possible arrangements of three colors. After each of them had found all six possibilities, I added a fourth color, and they tried again. The sister, who was younger, rapidly produced a dozen, and was still going. The older brother stopped at four, and declared that that's all there were. But look at what he had done. With three colors, he had made the arrangement shown in Figure 6.3. Now, into what he had already, he inserted the fourth color, in each of the possible positions as shown in Figure 6.4. It was *because* of his sense of system—his sense (which can only be called mathematical) that there was a fixed and necessary number of place-

Figure 6.3

R	B	Y
R	Y	B
B	R	Y
B	Y	R
Y	R	B
Y	B	R

Figure 6.4

G	R	B	Y
R	G	Y	B
B	R	G	Y
B	Y	R	G

ments—that he stopped there: The new color was in each possible position, within a system that had all of the other colors already in each possible position. It is true that his thinking left out one step, but nonetheless his was a far deeper understanding of permutations than his sister's facile but random generation of yet more arrangements that looked different.

Ways of Measuring—Productive and Unproductive

Getting closer to everyday concerns in the classroom, think of measurement. It can seem very straightforward—count the number of units that apply to some quantity and there it is, measured: so many foot-long rulers in a table, plus a number of inches; so many minutes in the running of a mile, plus a number of seconds. But take this example, for which I am indebted to Strauss, Stavy, and Orpag (1981): You've measured the temperature of one glass of water—100°; you add to it another glass of water, which is also 100°. What will the temperature be now? Most of our measurement experience would lead us to say 200°! And that is what a lot of children do in fact say—having easily understood *how* to add measurements together, but never having wondered *when* or *whether* to add measurements together.

Let me, by contrast, give some examples of invention of ways of measuring, which might seem tedious and inefficient, but which are thoroughly understood by their inventors. The first one deserves a better accounting than I can undertake here. In a class studying (once again) pendulums, children had explored coupled pendulums, set up like the example in Figure 6.5. If everything is symmetrical when you start one

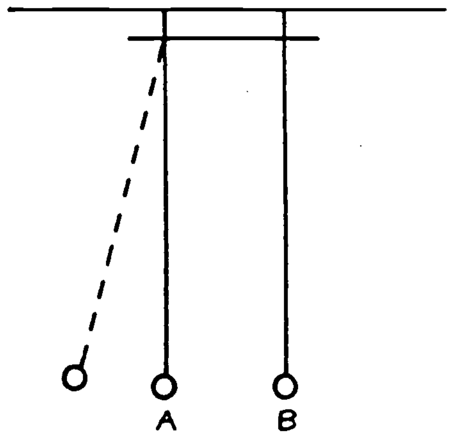

Figure 6.5

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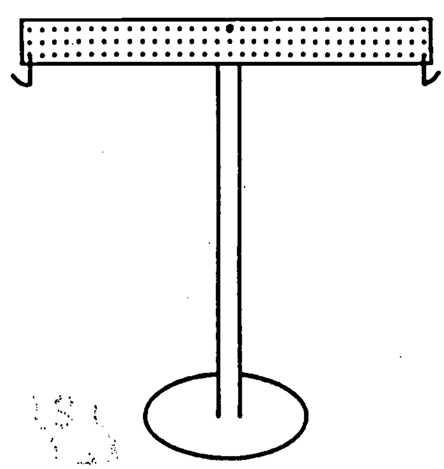
bob, then after a few swings the other bob starts to move; gradually bob *A*'s movement diminishes and bob *B*'s movement increases, until *A* is stopped and *B* is swinging widely. Then the movement passes back to *A*, and so on. Suppose, however, that everything is not symmetrical—the stick is tilted, or one string is longer than the other, or one bob weighs more than the other. In that case, the bob that starts swinging does pass some of its movement on to the other, but it does not come to a halt itself; the halts are asymmetric—they belong only to the bob that was at rest when the other started swinging.

That is a long introduction. The point is that in this class, a time came when the children were interested in comparing the weights of the wooden bobs and the steel bobs. Scales were available, and most of the children went to them. But Elliott, who happened to be the least scholarly child in the class, had a different idea. He set up a coupled pendulum, hung a steel bob on one string, and then added wooden bobs to the other, trying the coupled motion each time he added a bob—until, at four wooden bobs, the halts were alternating symmetrically from string to string. So he knew the four on one string must weigh the same as the one on the other. This astonishingly imaginative grasp of what it means to compare weights of things should be contrasted with the following tale.

In a different pendulum class, junior high school students had just previously been taught the equilibrium formula that applies to balances: Distance times weight on one side must equal distance times weight on the other. The only weighing mechanism available to them now was a strip of pegboard, supported in the center (Figure 6.6). When the students became interested in weighing the bobs, they hung a wooden

Figure 6.6



bob on one end, and then a steel bob on the other side, so as to make the pegboard horizontal, announcing, "There, they weigh the same. We learned that just last week, they weigh the same." It seemed clear that that formula had been hastily learned, and remained quite unexplored.

The next example comes from work done with Jeanne Bamberger and Magdalene Lampert at the Massachusetts Institute of Technology (Bamberger et al., 1981). We were working with a group of Cambridge teachers, helping them examine their own ways of knowing in order to better understand children's ways of knowing. One kind of knowledge we were exploring was music. They were building tunes, and at one point they wanted to know whether a tune they had built had sections that were the same length. They didn't know how to think about that. They tried to use a watch but couldn't tell from a watch whether the first half of the tune was the same length as the second half. This led us to invent time-measuring machines. We took a recorded tune, as the standard event, and they were to construct time machines (without using watches or clocks) to tell whether some other piece of music, which we were subsequently going to play, was as long as that first piece, or longer, or shorter. They all made what we called tune-specific time-measuring machines; that is, they did not set out to find some unit that would be repeated a number of times, but instead tried to make something that measured just the length of the standard piece: water dripping out of a cup, down to a line that indicated the end of the piece; or a candle burning down just to the end of the piece.

One team made a ramp of two pieces of metal, each about 4 feet long. To their dismay, the ball rolled off the 8 feet of ramp before the music stopped. They changed the slope; the ball still rolled off. They made a pathway on the floor at the end out of tongue depressors so that the ball could keep rolling along the floor, but now the ball stopped too soon. They changed the slope—very steep, barely any slope at all—but no matter what they did with the slope, the ball stopped too soon. They finally concluded that they would have to make the ball do something else after the roll down the ramp; otherwise they would simply have to abandon the ramp idea. So they moved the ramp up onto a long table, set it up with barely any slope at all, and arranged it so the ball could drop off at the end. Now what could they have it do when it dropped off? Casting about for available material, they took a pan from one of the pan balances, and suspended it at the end of the ramp, so the ball would fall into it (Figure 6.7). As the recorded tune started, the ball started rolling slowly down the ramp, fell into the pan at the end, thus setting it swinging, and at 32 swings of the pan the tune was ended. A single-

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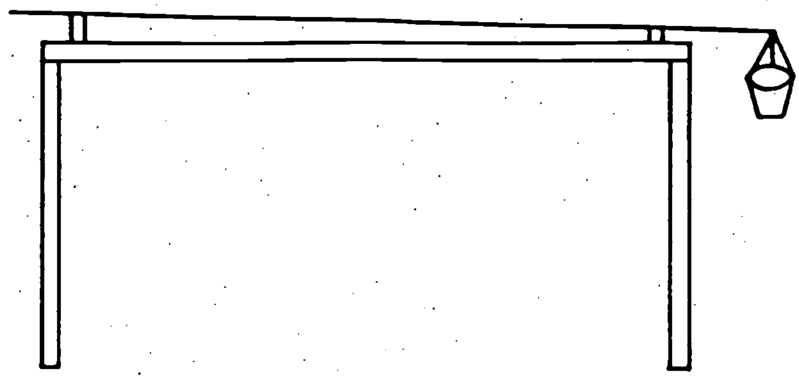

Figure 6.7

purpose time machine it was, but a perfectly dependable one—it was a roll down the ramp followed by 32 swings of the pan, every time. The tune that was to be compared with it, moreover, turned out to be a roll down the ramp followed by 37 swings of the pan; so their machine was shown to be adequate to its time-measuring task.

These stories can be thought of as comic relief. In a sense, they are. But the comedy of the coupled pendulum and the ball on the ramp is very different from the comedy of the 200° water and the misuse of the pegboard balance. The latter two are sad tales of too rapid assumption of understanding. The other two are the rather appealing consequences of avoiding such facile rapidity. How to measure can be taught rapidly, but when it is, the inadequacies are stunning. It is quite different from the breadth and depth of understanding involved in messily constructing your own ways of measuring, knowing what they mean, how they are applicable or not applicable, and how they inform each new situation.

Raising Questions About Simple Answers

Readers may think that any adult must of course know what time measurement is about, and that the only challenge in the work of these teachers was the technological one of getting some machine to work dependably. But it is worth reflecting on how you would know, without having some other ready-made timer, whether a candle burns with the same speed during its first quarter-inch and during its last quarter-inch. How do we know that a sweep second hand takes the same time for each one of its sweeps? How, back there in history, did anyone conclude that some event always takes the same amount of time, and so could be used to measure the time of other events? Without a standard unit, how did they establish a standard unit? This group of teachers gave those questions a lot of thought. And here is a question that gave them pause for a long time: One of them had heard that between five and seven in the evening, demands on electricity are such that electric clocks always run slower. Is that true? If it were, how would we ever know? If it is not, why isn't it? Wouldn't any time piece, in fact, keep going slower and slower as the battery wears out, or as the spring unwinds? As teachers, I think one major role is to *undo* rapid assumptions of understanding, to slow down closure, in the interests of breadth and depth, which attach our knowledge to the world in which we are called upon to use it. There may, for some given situation, be one right answer, even one that is quite easily reached. But I think a teacher's job is to raise questions about even such a simple right answer, to push it to its limits, to see where it holds up and where it does not hold up. One right answer unconnected to other answers, unexplored, not pushed to its limits, necessarily means a less adequate grasp of our experience. Every time we push an idea to its limits, we find out how it relates to areas that might have seemed to have nothing to do with it. By virtue of that search, our understanding of the world is deepened and broadened.

I would like to develop this thought in the context of the adult thinking of this same group of teachers. Having started with music and proceeding to measure time, they came to the study of ramps, and the main interest of this study was that they pushed the limits of what seemed to be ordinary, even obvious, thoughts about time, speed, and space.

The tune-specific time-measurement machines developed in the direction of a search for units of time measurement—calibrating the candle as it burned, counting the water drips, looking for natural phenomena that keep a steady rhythm. The search applied to ramps, too: Could a ball rolling down a ramp give rise to units of time? This led to another question, as a preliminary: What does the speed of a ball do as it rolls down a ramp? Does it remain constant? Increase? Decrease and then increase? Increase and then remain constant?

One group, watching a ball in order to make an initial guess about the answer, noticed a spot on it. The spot came up faster and faster as the ball rolled, until by the last part of the ramp its occurrences were no longer distinguishable—it looked like a blurred continuous line. This supported the idea that the ball was going faster and faster as it rolled down the ramp, but this group wanted to do a better job of it than that. It occurred to one of them that if the dot left a mark as it rolled they would be able to see better what the speed of the ball was doing. A bit of experimenting and they found a substance they could mark the dot with that would leave a spot each time it hit a long sheet of computer printout paper that was stretched down the ramp. The reader might want to predict what the spots did. We have since discovered that about half the adults we ask predict that the dots will get closer together, a few predict they will get farther apart, and the rest predict they will remain at a constant distance. The roll of computer paper with the spots left by the ball looked like the graph in Figure 6.8. The reaction of at least one member of the group was to take a piece of string and measure the distances, saying something to the effect of, "Gee, those dots don't get closer together as noticeably as I had thought they would!"

That turned out to be just the beginning of many perplexities in this consideration of speed-space-time relationships. Another group, also trying to establish what the speed of a ball does as the ball rolls down a ramp, produced the graph shown in Figure 6.9. At a subsequent seminar, the teachers who had been absent when the two graphs were produced were given the job of interpreting them—trying to establish how each had been made, and what each of them said about the speed of the balls rolling down the ramps.

I am not going to say here how the second graph came about. My purposes are better served if readers put themselves to the task—because in this case the answer to the ball-ramp problem is really beside the point; what I would rather do is make vivid how much harder it is to think coherently about space-speed-time phenomena than it is to enunciate formulas.

Here are a couple of the inferences made by the members of the original group. One person thought the spots on the first graph looked as if the ball had left its own mark as it rolled; but then, she went on to say, it would have to have been rolling at the same speed all the way, so it couldn't have been rolling down a ramp. The second graph was thought *not* to have been made by the ball itself. This inference was made not on

Figure 6.8

Figure 6.9

the basis of the distances between the marks, but because the marks looked as if they were drawn by a hand-held felt marker. One generally accepted thought was that marks were made indicating where the ball was after equal time intervals.

The discussion of these two graphs went on for two hours. The members of the group who had been present to generate them got caught up in considering what interpretations were possible in addition to those they knew to be the case. Does the first graph say anything about speed? Is anything to be learned by superimposing the first graph on the second? What picture would you get if you made both graphs at once, of one ball rolling down a ramp? What *does* the speed of the ball do in the second graph, anyway? The point of this work was to build a construction of space-time-speed ideas not rapidly, but solidly, and to know what the relationships are, after all, that are summed up in that easy high school formula. At the end of those two hours (which, remember, followed a number of other hours of experimental work and thought), no matter how I pushed the conclusions into paradoxical or counter-intuitional extremes, the teachers resisted. No one could be seduced by what sounded like a sensible thought if it did not fit into the idea-structure that they had created, in all of its breadth and depth.

Time for Confusion

One other topic that this group of teachers worked on was the moon. All of us know that the earth turns upon itself, the moon goes around the earth, and while both these things are going on, the earth is also going around the sun. All of us also see the sky get light and dark again every day, see the sun pass overhead, often see the moon, sometimes full and sometimes not. But how many of us can make a connection between these two kinds of experience? On a given afternoon in Massachusetts, for example, at 5:00, the moon was slightly less than half, and it was visible quite high in the sky. Now, in a model of sun, earth, and moon, could you place them in the relative positions to indicate where they would be in order for the sky to look like that? Almost nobody I've run into can do that. Those two kinds of knowledge about the moon are, for the most part, quite separate. Bringing them together, moreover, is a difficult job, which makes this a marvelous subject through which to study one's ways of making sense of one's experience, and especially to realize how a simple formal model can have almost no connection with the experience it is meant to describe.

It takes months of watching and finding some order in the motions before one can know, when looking at the moon, in what direction it will move from there; where it will be an hour later, or 24 hours later; how the crescent will be tipped 2 hours from now; whether it has yet reached its highest point of the night; whether, tomorrow, it will be visible in the daytime. Does the moon pass every day straight overhead? Does the moon ever pass straight overhead? Does it depend on where you are on the earth? If, right now, from here, it was up at a 70° angle from me, at what angle would it be if I climbed up to the top of that building? If I were sitting down, at what angle would it be? Or if I walked down the block toward it?

One friend claimed he had seen the moon like the drawing in Figure 6.10. How was it possible, he asked, for the round earth to have cast a crescent-shaped shadow on the moon? He could understand seeing the moon itself like a crescent, as in Figure 6.11, but he could not understand what he claimed to have seen. It is a good question for moon-watchers, and I put it to the readers, with what seem to me three possible explanations: Either he did not see the moon shaped that way; or there are circumstances under which a sphere (the earth, in this case) can cast a crescent-shaped shadow; or the crescent that is missing from the side of the moon is not the shadow of the earth.

Another friend confessed how perplexed she had been when she realized that people standing on the moon looked *up* to see the earth. Surely, from the moon, one should look down at the earth if, from the earth, one looks up at the moon? Figuring out that puzzle for herself was a source of considerable joy.

In our seminar, moon questions took us into sun-earth questions that were no less difficult. How, with models of earth and sun, do you represent the sun coming up over the horizon? What is the horizon, anyway? If the sun is, for you, on the horizon, where is it for everybody else? If the sun is straight overhead at noon (and *is* it straight overhead at noon?), is it straight underfoot at midnight? If the sun's rays go out in all directions, past the earth, can we see them? Does that mean that the part that is in darkness on earth is smaller than the part that is in light?

One of the teachers drew on the blackboard this picture of the earth

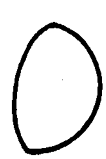

Figure 6.10

Figure 6.11

in the midst of the sun's rays (Figure 6.12), and was trying to articulate her thoughts about it. Another member of the group was asking her to be more precise. Did she mean *exactly* half the earth was in darkness? Did it get suddenly black at the dividing line, or was there some gray stripe? The one who was trying to articulate her thoughts grew angry, and gave up the attempt. She said later that she knew the questions were necessary at some point, but she had not been ready to be more precise. She was struggling to make sense of a morass of observations and models, an idea was just starting to take shape, and, she said, "I needed time for my confusion."

That phrase has become a touchstone for me. There is, of course, no particular reason to build broad and deep knowledge about ramps, pendulums, or the moon. I choose them, both in my teaching and in discussion here, to stand for any complex knowledge. Teachers are often, and understandably, impatient for their students to develop clear and adequate ideas. But putting ideas in relation to each other is not a simple job. It *is* confusing; and that confusion *does* take time. All of us need time for our confusion if we are to build the breadth and depth that give significance to our knowledge.

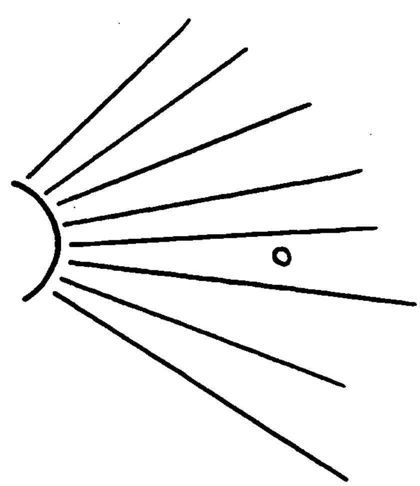

Figure 6.12

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DON'T TELL ME HOW THINGS ARE, TELL ME HOW YOU SEE THEM

Ricardo Nemirovsky[8]

The teacher had set up today as a deadline for each team of students to decide on a project to develop. But it turns out that most of the teams have not decided yet. Team A, for instance, is discussing several possibilities that it found in different books: a demo about magnetic damping, a demonstration of how an electric motor works, and an electronic circuit to generate waveforms. But all of them seem uninteresting or too mundane. The students in Team B are excited about the possibility of constructing a laser. They got the idea from an article in *Scientific American*. But they do not quite understand how to do it.

This essay was originally conceived as an analysis of common difficulties arising in project learning. More specifically, as an exploration of some patterns in students' attitudes toward the selection of "what to do," as an attempt to unfold what these attitudes may be expressing. They are exemplified by the Teams A and B in the scenario just described. As I wrote and articulated my ideas, a theme emerged as the center of this inquiry: the sense of wonder about the world around us. Slowly I began to envision the critical relationship between project-enhanced learning and the sense of wonder about the world

Each time a teacher decides to organize project-enhanced learning, she or he is reflecting a particular perception of science education and of her or his students' needs, namely, to create a learning atmosphere that resembles how scientists work. One of the most widely shared hopes behind the organization of project-enhanced learning, is to foster intellectual autonomy in students. This goal highlights the importance of giving students the freedom to choose what to do. To the naive observer it seems really straightforward: You provide some guidelines and just ask the students what they want to do. What happens next? A few students are very responsive. They have clear ideas and some can lead their team of classmates. But for many students the situation is very unsettling. Some of them may be characterized as the "Bored" ones. Nothing seems to trigger their commitment, and every idea that is discussed ends with a "nah." Often they are driven to an "I don't care" attitude, selecting whatever looks simple and easy from books or teachers' descriptions.

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Others may be called the "Spectacular" students. They are only moved by sensational projects that will impress the audience during the final presentation. Sometimes their ideas are unfeasible. They have a hard time assessing the cost, time, and expertise demanded by the ideas they want to pursue. Other times they have difficulties infusing their impressive performances with science content and are forced to add some irrelevant explanations alluding to "Newton's laws" or "electrostatic forces." Among all the patterns in students' attitudes toward the selection of a project, I believe that the Bored and the Spectacular ones reflect two sides of the same coin, which is: How hard it is to wonder about the world around us.

On the Sense of Wonder

Every child, until she or he is 5 or 6 years old, shows a never-ending sense of wonder about the events that affect her or his life. Something fundamental changes along the path toward adulthood. A gap grows between child-like and adult ways of knowing. When a child asks why the trees do not walk or why the moon is white, something magic is triggered in an adult's mind. It is like an awakening from a dream, because we sort of know that trees do not walk but...how come one can wonder about that? A more unsettling feeling may follow as we realize that we don't have good answers. Children help us to shake what we take for granted; in a way this "taking for granted" is a key to understanding the nature of the child–adult gap. We adults learned to see the world around us without the perception of strangeness. Strangeness recedes into the distant and the unusual. The everyday world becomes obvious. The common experience moves to an invisible background.

However, when we become adults the 5-year-old child does not disappear. Howard Gardner (in preparation) said that in every adult there is a 5-year-old child struggling to emerge. Moreover, he claimed that this struggle is behind some of the most extraordinary creations of the arts and the sciences. It takes an enormous effort to become aware of the strangeness of the everyday world, an achievement that has been described as the recovering of the child's vision. I do not see any role for science education more important than the preservation and enrichment of this childish perspective on nature, of the ability to develop a fresh look at common things. When this does not happen, when we become incapable of wondering about the world around us, our search for amazement and excitement necessarily lead us to the distant and the unusual; the immediate comes to be self-evident and ultimately invisible. A new dichotomy begins to encompass our relation with nature: boredom or spectacularity, the triviality of the immediate or the hard-to-believe behavior of the remote.

There are basic differences between amazement and wonder. In pondering the nature of something it is very different to say "I wonder" than "This is amazing." The locus of wonder is in the knower, whereas the locus of amazement is in the event or thing. Amazement is a reaction to an unusual event that happens "out there," whereas wonder is born from our inner perception of puzzlement. In trying to revitalize the students' interest in science there is a trend to substitute the feeling of amazement for the sense of wonder. Sometimes they are connected. Amazement may elicit wonder, but this link is not a necessity. Amazement can dissolve without wonder. This is evident in many science museums' exhibits. It is not unusual to see people running from device to device, pushing buttons compulsively expecting to see something amazing happen. If this does not take place quickly they run to the next. I was told by a science museum officer that the rule of thumb is 30 seconds. If, after 30 seconds, nothing amazing has taken place then the exhibit has failed to catch the attention of visitors.

An element that suffocates the sense of wonder is the pervasive perception that things are explained by theories. Polanyi (1964) was a very eloquent critic of this perception. He argued that things are explained by people. Science is not in the books, it is in the human activity of making sense. Moreover, he articulated the point of view that science resides in the personal knowledge of its practitioners. Personal knowledge does not refer just to what individuals have "in their heads." Personal knowledge is acquired through immersion in social practices, through apprenticeships, communication, and the use of the tools and symbols that are built in a cultural environment. Through participation in scientific communities, the tools and symbols of scientific discourse become transparent, subsidiary, and therefore "personal." In other words, personal knowledge thrives through one's participation in cultural forms of knowing.

Large domains of personal knowledge are necessarily tacit. An example may help to clarify this notion. The example that I use (that is common in the literature) is our knowing what is an appropriate physical distance between people. We express rich knowledge about this issue in our day-to-day interactions. We know how to adjust our closeness according to the situation: if the relation is more or less formal, if the environment is more or less noisy, if we are in a group, and so forth. We also may interpret some attitudes from "the other" as telling us that we are too close, or too far. This body of knowledge is tacit. We can talk about it, we can make theories about it, but our acting out of distancing from others cannot be reduced to our talking about it. Actually, our talking is a reflection on our experience of what it is like to behave appropriately. As we become skilled, as we enrich our personal knowledge full of tacit components, our talking becomes more and more meaningful.

To learn science or mathematics implies the construction and refinement of many tacit components of knowledge. For instance, the grasping of what it means to prove something, what are pertinent science questions, or how to make sense of an experiment, are largely tacit. Sometimes we expect the contrary, namely, that being exposed to formal descriptions and explicit accounts of theories, are the bridges toward the thriving of personal knowledge, rather than the latter being the condition for a meaningful discourse. David Goodstein, in an issue of *Physics Today* devoted to the memory of Richard Feynman, recalled:

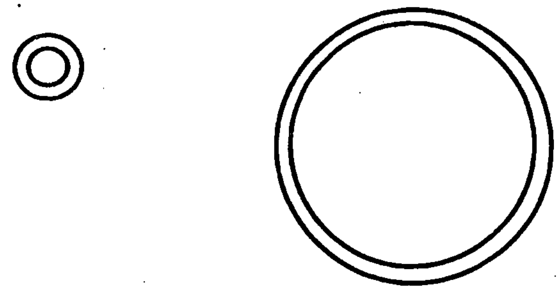
> In all those years, only twice did he teach courses purely for undergraduates. These were the celebrated occasions in the academic years of 1961-62 and 1962-63 when he lectured...on the materials that were to become *The Feynman Lectures on Physics*.. As the course wore on, attendance by the kids at the lectures started dropping alarmingly, but at the same time, more and more faculty and graduate students started attending, so the room stayed full, and Feynman may never have known that he was losing his intended audience....The lessons in physics he prepared, the explanations of physics at the freshmen level, weren't really for freshmen, but were for us, his colleagues...It was more often us, scientists, physicists, professors, who would be the main beneficiaries of his magnificent achievement, which was nothing less that to see all of physics with fresh new eyes. (Bartlett, 1992, p. 67)

Feynman's lectures, rather than explaining physical phenomena to novices, deepened the physicists' understanding of their own practices.

However, there is a common view that scientific ideas can be explained beyond practices, beyond human activity, and that they dwell in the statements printed in books and journals. This has led people to think that there is something that we may call the "Official Explanation of Things" (O.E.T). When the students' personal knowledge is inconsistent with the O.E.T, science education is supposed to fix it. For example, during the 1970s and 1980s researchers discovered all sorts of inconsistencies of the kind that are extremely difficult to overcome. They were called "misconceptions." This research movement produced compelling evidence that naive approaches to natural phenomena are sensible, structured and complex.

One of the pictures that grew out of that research movement is somewhat grotesque: Students stubbornly resist adopting the O.E.T., preferring to use their own, often mistaken conceptions. Consequently, the role of the teacher is to convince students that the O.E.T is the right way of thinking. Teaching in this mode is interpreted as convincing, as an effort to undermine students' arguments for holding their misconceptions.

The focus of science education on students' internalization of the O.E.T weakens the sense of wonder, just as the focus on amazement does, because it frames science as external, in the things or in the books. The knower's activity remains legitimate to the extent that it fits the established truths of the O.E.T. Seymour Papert (1980) analyzed a mathematical problem that may illuminate some of these issues. Suppose we pose the following problem: A string forms a circle whose radius is 2 inches. Imagine another circular string with the radius of the earth. How much more string do you need to enlarge the radius of each circular string by 1 inch?



The fact that you need to add the same length of string in both cases is extremely counterintuitive. It is not hard for another person to convince us that it is the same. She or he can use some basic facts, such as the formula for the length of a circumference, to show that the length of string that has to be added is independent of the radius:

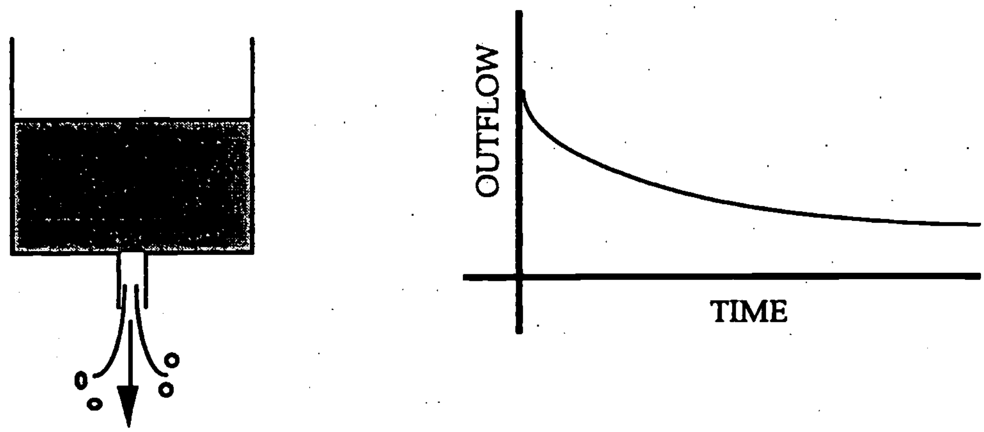
$2\pi r = l$

$2\pi (r+\Delta)=l+2\pi \Delta$ —> the difference is $2\pi \Delta$, for any radius r.

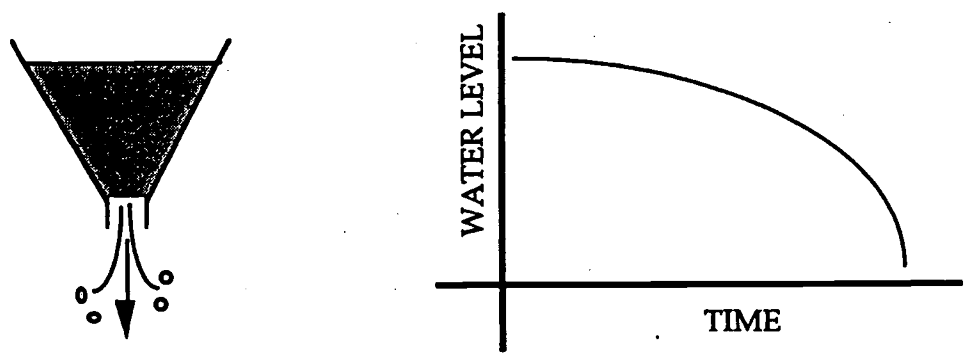
The only thing that matters is the change of radius. But even if she or he is successful in "convincing" us, still the issue is unresolved: What is it about our way of thinking the problem that leads us not to expect such a result? Without pursuing this inquiry, without exploring the nature of our personal knowledge, it is likely that a change of the conditions of the problem will elicit the same initial expectation. It is possible that many "convincing" demonstrations affect the students' sense of their own abilities to understand science more than students' actual understanding of science. It is not a matter of "stubbornness" or not wanting to accept the O.E.T, it is the fact that we do not have any way to know beyond our personal knowledge.

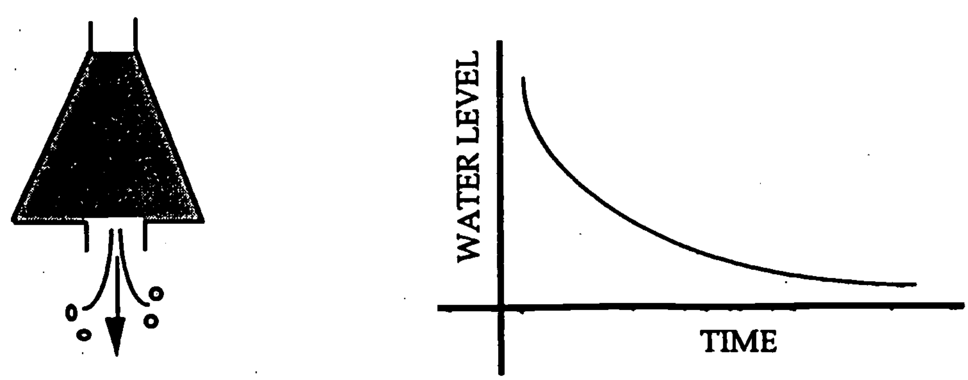
If the hard-to-believe demonstrations, or compelling O.E.T pronouncements do not help to nurture the sense of wonder, what does? I believe that the sense of wonder is activated when our own way of thinking about the world becomes an object of our inquiry, when we become aware that things may cease to be obvious as we change our "knowing" perspective, when we recognize that it is not just a matter of how things are, it is also a matter of how we envision them. I describe an episode with a high school student who is puzzled about different aspects of water flow. It shows a student experiencing the obvious becoming unexpected. No galaxies, no black holes, no quarks, just water flowing out of common containers.

This was the fourth session during which Elisa, a high school student, had worked with water flow. She had experimented with different containers, measuring different regimes of inflow and outflow. In this session, Elisa predicted that the curve of rate of outflow versus time for the water flowing out of a cylindrical container would display this shape:

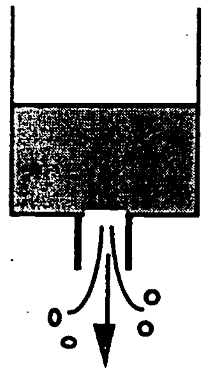


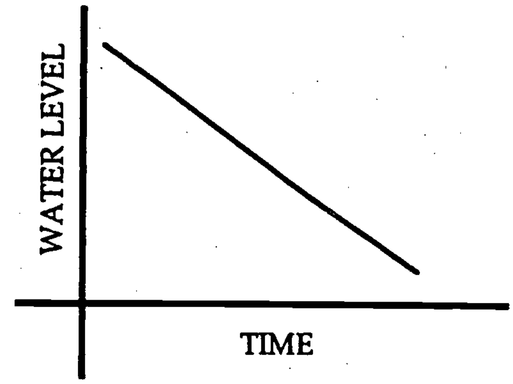
Her prediction was based on the notion that the water inside the container "pushes" the water flowing out, so as water flows out, and the water level decreases, the "push" will be smaller. On the other hand, she predicted that the water level would decrease linearly. That is, the curve of water level versus time would look like a descending straight line. This intuition was elicited by noticing a symmetry. She had observed that the funnel and the Erlenmeyer flask produced the following graphs:





Therefore, a cylinder, which is in the middle between a funnel and an Erlenmeyer, would produce a straight line.





We were discussing the process by which she calculated the outflow taking differences of water level:

> Ricardo: Then if you have a straight line, what would you expect, taking differences at regular intervals?
>
> Elisa: That it would be the same....If it wasn't the same, then...the difference should be the same. It's supposed to be. Is it? If that one [water level vs. time graph] is really a straight line, then, if that one is really a straight line, then the other one [the outflow vs. time graph] is really a straight one [gesturing a horizontal line], basically, because if it makes a difference in the outflow, then it has to make a difference in the level versus time, because then it would make a difference in how much water's going out at each point
>
> Ricardo: That's important then.
>
> Elisa: So then, one of them has to be wrong. One of our predictions has to be wrong...if the outflow is first high and then gets leveled...then the level can't go straight like that.
>
> Ricardo: Cannot?
>
> Elisa: No, it cannot, because if the outflow's high, then the level has to decrease fast. When the outflow gets less, then the level has to decrease slower....Either this one or this one [of the predictions] has to be wrong...or both of them.

The heart of Elisa's puzzlement about the behavior of water flowing out of a container is in how to think about it and in her awareness that two conflicting intuitions, the water push and the figural symmetry, struggle to emerge in her attempt to make sense of the situation. Her wondering is part of an ongoing process of reflection on the unintended results of our joint experimentation with water and containers. A measurement of the "real" curves of water flow and level versus time, won't be the end but the beginning of new reflections. Suppose that she measures and gets an experimental curve indicating unambiguously that her prediction of outflow versus time is "right." What to do with the idea of symmetry? Just forget it? No, there has to be (why am I so sure?)—a certain shape for the container such that the water level decreases linearly, which one is it? Moreover, how does the shape of the container affect water flow?

Elisa, like most of us, has plenty of experience with water and containers. It is this expertise, sharpened by the work that she did during the previous sessions, that stands behind her intuitions. This kind of expertise is an essential part of the wondering about something. We wonder about what we know. What could I wonder about quarks? Nothing. I do not have expectations about them. Usually the media identify things like quarks, or any other exotic entity or procedure, as dwelling on the "edge of knowledge." But this way of labeling ideas conceals the fact that each one of us has different edges of knowledge. For example, Elisa, as she articulates her expectations about water flow, is experiencing one particular edge of her knowledge.

This reminds me of something that happened to me recently. I was eating an orange and I noticed that it was seedless. I had eaten seedless oranges before, but this was the first time I wondered about them. How do they manage to grow orange trees that do not produce seeds? How do those trees reproduce? Or how can they inhibit the tree from creating seeds? My experience with fruit and my expectations about the role of seeds in the reproductive cycle made me realize, as has happened to Elisa in the former episode, that there was something to be revised in my way of thinking about this matters, something important to be learned. The following day I asked a colleague who is a biologist about seedless oranges. He helped me realize that there is a possibility that I had not envisioned before: Fruit can grow before the seed is born. Perhaps the fact that seeds are usually inside a fruit had induced me to assume that it must grow around a seed, and therefore after the seed comes to be. In any case, the point is that the seedless oranges were at the edge of my knowledge. Edges of knowledge can be found around anything we know something about. Because in the end nothing is trivial. Triviality is an illusion that we adopt whenever we take something for granted.

Genuine Inquiry

At some point in our lives we all have the insight that when someone asks something, teachers in particular, often it is not because she wants to know the answer, rather it is because she wants to check whether we know what she assumes to be the correct answer. I will call "genuine inquiry" a mode of engagement in which his insight is *not* enacted; in which there is no sense of "simulation" and any question that is uttered reflects a personal wish to learn something from the other's perspective. I want to claim that genuine inquiry has a fundamental role in fostering the sense of wonder about the world around us.

There is an intimate interplay between wondering about the world around us and wondering about how we understand things.

> The general form of propositions is: "This is how things are"—This is the kind of proposition that one repeats to oneself countless times. One thinks that one is tracing the outline of the thing's nature over and over again, and one is merely tracing round the frame through which we look at it. (Wittgenstein, 1958, p. 48e)

This movement from "how the things are" to "how we frame things" triggers the sense of wonder. Wondering about our ways of understanding thrives as we deal with how different people, including ourselves, come to understand something. Genuine inquiry creates a communicative atmosphere that promotes the flourishing of these attitudes.

One may ask oneself: How is it possible to nurture genuine inquiry when one *knows* something? For example, if I ask myself whether a student knows Newton's first law, I cannot act as if I myself want to learn Newton's first law—it is too late, the question *cannot* be genuine. I think that this is true. The question "What is Newton's first law?" from someone who is a "knower" of Newton's laws, is not genuine. However, and this is central, it is certainly not genuine if the questioner refers to the statements of the O.E.T, that is, to what the textbook states under the title of "Newton's First Law." But if we shift our inquiry to how one can come to make sense of "Newton's First Law": How can one be sure (or not) of its validity? What does not make sense about it, or why it is so difficult (or trivial) to grasp? In other words if we move from "this is Newton's First Law" to "how does the Newton's First Law play in my understanding of things" AND if we realize that no two people make sense exactly in the same way of Newton's First Law, then the inquiry may become genuine.

Why do I say "it *may* become genuine"? First of all, because there are no recipes: It is not a matter of the *form* of the questions. It is a matter of really wanting to know how the student imagines things, and it is also a matter of throwing oneself into the scene. That is, of sharing our personal knowledge as such—as personal knowledge. Let me elaborate. It is common to hear conversations among teachers about what to do when a student asks something and you do not know the answer. It is a typical statement of progressive education that the teacher should honestly be able to say "I don't know" without feeling that something wrong is going on.

But it is much less common to hear about the broader issue, about the importance of personalizing knowledge. To answer "I don't know" is an act of personalizing knowledge, but as an isolated response it is reactive rather than proactive, it is not part of a general attitude. Personalizing knowledge involves talking about ideas manifesting their genesis ("I have not always thought in this way"); their tentativeness ("let me try to envision other possibilities"); their images ("I see it in several different ways"); and, their limits ("It does not help me to..."). Personalizing knowledge is a way of talking that situates expert and novice approaches in a continuum, rather than in the two opposite sides of a gap.

By saying "it is a matter of really wanting to know how student imagines things" I imply two things: First, that one does *not* know a priori how a certain student imagines things. Second, that one may learn something *new*, about us and about science or mathematics, by knowing how a student imagines. Some people who are familiar with the literature on students conceptions act as if all that is needed is to master the published taxonomy of conceptions. It is as if, say, you should ask the student to draw the forces acting on a flipping coin and then you categorize the student according to the answer A, B, or C. I think that it is useful to know about the research in this field, but not in order to substitute genuine inquiry, not in order to adopt published results as an O.E.T. Suppose that you ask a European his nationality. You can categorize the possible answers (Italian, French, etc.). He tells you that he is Italian. Would this "test" obliterate the need to talk about his personal experience? Would you assume that you know all about him? No two people arrive at the same answer A or B through the same personal experiences.

I do not deny that some techniques, such as how to word certain questions, may be of some help in fostering genuine inquiry. But there is a latent conflict in focusing on techniques because some readers will take form for substance and the message will be totally misunderstood. Because the same question, even the same words, may convey profound differences in what Carl Rogers (1969) called "attitudinal qualities." Let me introduce an example: In teaching there is an extremely common attitudinal quality that we may call "guess my mind." The teacher poses a series of questions and clues to "guide" the students toward a specific idea or answer that she or he has in mind. The students get involved in the communicative game trying to guess the hidden idea. This attitude may be of value in many circumstances but it does not help to promote genuine inquiry. It tends to structure the whole activity around a fixed piece of knowledge owned by the teacher.

When I *find myself* in a "guess my mind" stance while I am trying to encourage genuine inquiry, I tend to do one of two things (sometimes I do have this attitude but I do not find myself doing it, so I keep doing it): First I might speak my thoughts and say things like "you know, to me this is so and so, what is it for you?" But often if I state my own perspective it may prevent the other from pursuing her or his own approach. An alternative that I use is to *go beyond* what I have in mind, asking myself something like "What is it about the situation or about our prior experiences that we see it differently?" Exploring this question helps me to come up with overt questions, observations, and gestures that engage both of us in trying to understand what moves us to see things in a certain way.

Now I can use this example to illustrate the initial point: The same word may convey different attitudinal qualities—for instance the word "why?" In a "guess my mind" attitude, "why?" may mean: "I know why this is so and so, but I want you to figure it out for yourself. Look at what I'm pointing at, that is a clue, so tell me...," whereas in a genuine inquiry attitude it may mean: "Why do you see it in this way? I see it in a different way and I cannot picture your point of view, so, try to help me" These two meanings may be discriminated by the tone of voice, facial expression, gestural movements, and so forth, but rather than elaborating on facial expressions it is much more productive to talk about the kind of feelings that move us on to genuine inquiry.

With some people it is much easier to engage in genuine inquiry than with others. Through my experience interviewing students I have noticed that this is not related to school performance. I believe that a major determinant is to what extent the student feels that her or his own personal way of approaching something is worth looking at. When one strives intensely to articulate what "goes on in my mind" we become immediately aware of how distant it is from the closed and neat discourses of the kind that shape textbooks and lectures. Ideas and images seem to come from nowhere faster than we can keep track of them; understanding appears fragmented and partial; moments of insight alternate with feelings of being lost; and, frequently one gets caught in the middle of saying something that, suddenly, means nothing.

Some students, instead of interpreting these disjunctions as a manifestation of how subtle, rich, and complex is our sense-making activity, take them as showing ignorance and incompetence. They do not grasp that books and lectures in closed form result from an intensive struggle to *deny* the fleeting nature of human thinking. Even though there are many very good reasons to pursue such a denial, the permanent exposure to these "models" of good thinking has secondary effects that have been dramatically exacerbated by misuse. One of them is a tendency to deny our own ability to think. Our self-esteem, as beings that are able to make sense of the world around us, drops because knowledgeable discourse seems to be out of reach. Reliance on experts, textbooks—on the O.E.T.—emerges as an inescapable substitute of making sense by ourselves.

Sometimes the difficulties in creating genuine inquiry go beyond the individual participants, because in any relationship there are expectations given by the social context. Brousseau (1986) coined the term *didactical contract* in reference to a series of tacit expectations that guide the classroom behavior. They are written nowhere but they are still there. It may be part of the contract, for example, that the teacher will define what to do, that the students should tell the teacher what they know, that the teacher will determine how well the students are doing, and so forth. Some didactical contracts include expectations that are incompatible with genuine inquiry and, if that is the case, genuine inquiry may happen only as part of a renegotiation of the contract—at least a temporary one. A teacher cannot always renegotiate the contract. Lack of support from the system or lack of tradition may pose serious obstacles. Sometimes the organization of project-enhanced activities opens opportunities for a temporary predominance of an alternative contract.

It is clear then, that there are many possible reasons for the fact that genuine inquiry is unusual in the school practice. I believe that to talk and reflect about genuine inquiry is so important because it is so uncommon. Should genuine inquiry be the only, or permanent, mode of interaction? I do not think so. This reminds me of Peter Sullivan, an Australian researcher in math education who is working on an investigation about the role of open-ended questions in the learning of mathematics. He was reporting many interesting findings and one of his marginal comments was, "after a while the kids got sick of open-ended questions." Learning seems to require all kinds of modes of engagement. Closed questions also have important roles to play. Recipes are often powerful means to get unstuck, or to begin something new. A "guess my mind" attitude may trigger intriguing games. Genuine inquiry is a fundamental way, but not the only way, to help each other to learn.

Among all the modes of engagement for learning, genuine inquiry offers a unique contribution. One that goes beyond the learning of particular aspects of science or mathematics. It helps us to grasp the human dimension of knowledge. By noticing and sharing how we come to understand something, the shallowness of triviality dissipates, letting us to recognize how strange and wonderful is the world around us.

Article 8

What's All This Talk About Discourse?

Article 8

ARTICLE 8: What's All This Talk About Discourse?

Ball, D.L. (1991). What's all this talk about discourse? *The Arithmetic Teacher*. November 1991. 44-47.

Ball discusses some of the ways in which the *Professional Standards for Teaching Mathematics* (NCTM, 1991) might be used to open up conversations about mathematics teaching and learning. Using an example from her classroom of third grade students learning fractions, she illustrates the kinds of questions, considerations, and ways of thinking about her teaching practice that the NCTM Standards document raises for her. Ball describes how interactions between teachers and students shape classroom norms of knowing and thinking and urges teachers to examine the patterns of discourse in their classrooms. In particular, she discusses how focusing on the ways in which students' talk and thinking is valued and on the amount of time allotted to students for exploration and investigation can be critical in fostering the kinds of classroom talk put forth in the standards.

Questions

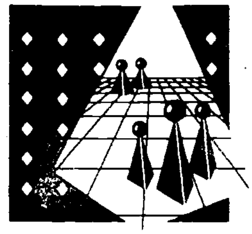
- What does Ball say about the role of the "Professional Standards for Teaching Mathematics" (NCTM, 1991) in classroom work? Do you agree with her viewpoint? Why or why not?

- Ball writes about "discourse" in the classroom. What does she mean by "discourse? How does she say that teachers shape the discourse in their classrooms? What else does she say shapes the discourse in a classroom? What kinds of questions does she raise about her own ways of talking in the classroom? about the ways of talking among her students? Are these questions helpful for you in thinking about your teaching practice? How?

- What does Ball say about wrong answers? Do you have any examples from your classroom in which a student's wrong answer helped you see or understand something differently?

- Ball gives an example of a conversation in her classroom accompanied by her own "mental discourse" — the questions she has about the decisions she makes as a teacher. Try reading through this illustration aloud, each member taking a part — including Ball's internal dialogue. Can you relate to the dilemmas Ball expresses throughout this discussion? What do you think her students are learning about mathematics? Do you think there is value in this kind of conversation in math? Why or why not? Do you think there is value in this kind of teacher reflection? Why or why not? What forms might it take in your own practice?

IMPLEMENTING
THE PROFESSIONAL
STANDARDS FOR
TEACHING
MATHEMATICS



What's All This Talk about "Discourse"?

Despite its title, the *Professional Standards for Teaching Mathematics* (NCTM 1991) should not be read as a set of prescriptions about how to teach. The document will not deliver on such expectations, not because it fails but because no document can prescribe good teaching. No set of standards can be expected to stipulate what teachers should do. The potential of the *Professional Teaching Standards* rests instead in its use as a set of tools with which to construct productive conversations about teaching. It should be viewed as a resource with which to build teaching rather than as a measuring stick by which to judge teaching. With new ideas about things to pay attention to in our classrooms, to ask ourselves, to wonder about, we would have increased power to analyze and improve our teaching — alone and as members of a wider community of educators. In this article I explore possible outcomes of using the *Professional Teaching Standards* in such ways.

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The Editorial Panel welcomes readers' responses to this article or to any aspect of the Professional Standards for Teaching Mathematics *for consideration for publication as an article or as a letter in "Readers' Dialogue."*

Discourse in the Classroom

The *Professional Teaching Standards* calls unprecedented attention to the "discourse" of mathematics classrooms, as embodied in three standards: Teacher's Role in Discourse, Students' Role in Discourse, and Tools for Enhancing Discourse. An unfamiliar term to many, *discourse* is used to highlight the ways in which knowledge is constructed and exchanged in classrooms. Who talks? About what? In what ways? What do people write down and why? What questions are important? Whose ideas and ways of knowing are accepted and whose are not? What makes an answer right or an idea true? What kinds of evidence are encouraged or accepted?

The discourse of a classroom is formed by students and the teacher and the tools with which they work. Still, teachers play a crucial role in shaping the discourse of their classrooms through the signals they send about the knowledge and ways of thinking and knowing that are valued. For example, suppose a student claims that in tossing a penny, heads is a more likely result than tails. He explains that in ten throws, he got seven heads and three tails. He says that this outcome shows that it is "easier to get" heads. How might the teacher respond to this statement? Knowing herself that heads and tails are equally likely, she might tell him thatthis conclusion isn't right and explain that the outcome he noted was simply what happened that time. Or she might ask other students to respond to his assertion, for across the entire class the cumulative results of tossing a penny will probably turn up approximately half heads and half tails. Or she might observe that ten throws is not very many and suggest that he gather more data himself to see what happens. In each of these alternatives, different messages are sent about the usefulness and validity of the student's experience with coin tossing. Each conveys different implications about the role of experimentation in constructing mathematical knowledge, and each may have different effects on the student's view of mathematical justification. This small example illustrates how influential teachers' interactions with students are in shaping norms of knowing and thinking. These interactions, in turn, influence students' ways of knowing. The norms that students and teachers come to share deeply affect the potential of the classroom as a place for learning.

Without explicit attention to the patterns of discourse in the classroom, the long-established norms of school are likely to dominate — competitiveness, an emphasis on right answers, the assumption that teachers have the answers, rejection of nonstandard ways of working or thinking, patterns reflective of gender and class biases. For example, in many mathematics classrooms, answers have traditionally been right because the teacher says so or because the teacher and the student together decipher what "they" (the textbook authors) "want." Even with careful attention to patterns of classroom discourse, traditional norms will underlie the interactions of students and teachers. Consider the way in which right answers are treated in a mathematics class. Suppose students are solving the problem "What is two-thirds of nine?" and a student gives the answer, "Six." The teacherly reflex is to hear it as a "right answer" and to (*a*) move on; (*b*) praise the student; or (*c*) agree and repeat the answer for the benefit of the rest of the class. Even disposed to ask students to explain their answers, the teacher may ask, "How did you *know* that?" In listen-

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ing to myself in my own classroom, I realized that using the word *know* seems to imply that the student's answer is right. I heard myself saying, "How do you *know?*" when I agreed with what a student said and asking, "Why do you think so?" or "How did you get that?" when I did not. Subtly, I was probably giving my students clues about the "correctness" of their ideas — clues they were likely picking up.

When we hear right answers simply as representing understanding, we miss opportunities to gain insight into students' thinking. A student could get six as the answer to "What is two-thirds of nine?" by using the following reasoning: two-thirds means two groups of three, which is six. Although interesting, this is not the conventional interpretation of two-thirds. Similarly, when we hear wrong answers as representing a lack of understanding, we also miss the opportunity for valuable insights. Some wrong answers are produced by simple errors, whereas others represent well-developed concepts or ways of thinking — some productive and some less so. For example, a student in my class was convinced that two-thirds was less than one-sixth. I could have interpreted this perception as a problem with her ability to compare fractions with unlike denominators or suspected that she was thinking that 1/6 was more than 2/3 because it has a "6" in the denominator, whereas 2/3 hasonly a "3" (and 6 is more than 3). Instead, she was reading 2/3 as "you have three parts and you take two of them away" and 1/6 as "you have six parts and you take (only) one of them away." Her reasoning about fractions was complicated with subtraction concepts that led her to believe that more was "left" in one-sixth than in two-thirds. Had I not explored this student's answer with her, neither I nor the other students would have understood the thinking that led to her conclusion.

The classroom environment, or culture, that the students and teacher construct affects the discourse in some important ways. The environment shapes how safe students feel, whether and how they respect one another and themselves, and the extent to which serious engagement in mathematical thinking is the norm. Are students' voices and thinking valued by the teacher and by other students? What norms are established for the exchange of

FIGURE 1

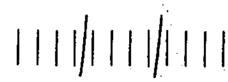
A third-grade-class discussion and teacher's mental discourse

It is a warm mid-May afternoon. My third graders have been working on the problem "Three-fourths of the crayons in Mrs. Rundquist's box of a dozen crayons are broken. How many unbroken crayons are there?"

I have a very diverse class, with several students who are just learning English. Is this problem one that all my students can engage in reasonably?

A boy named Sean offers to show his solution. "It would be four," he asserts as he comes up to the chalkboard. He draws twelve sticks to represent the twelve crayons and marks off groups of four crayons:

I always wonder about whom to call on to start off our discussion of a problem. Who should have the floor first and why?



Accepting drawings like this one seems important to expand the tools that students can use to think with as well as to express their thinking.

He explains, "Well, I, um, counted these and I got, I went, 'One, two, three, four,' and I put a line down. So it's . . . then I went, 'One, two, three, four'; and I put another line down and I add them up and it's eight; and I put another line, 'One, two, three, four.' And that was twelve." He finishes. "Why . . . " I begin to ask, but Sean interrupts, changing his mind. "A quarter wouldn't be *that*." He erases the lines, "Because, um, because that's a *third*. There's only three groups. There's supposed to be *four* groups." Sean draws lines to mark off four groups of three crayons:

I am glad to see that Sean expects that part of showing his solution is to explain what he did and what he was thinking.

I am always interested when students figure out for themselves that something doesn't make sense. How to set up the environment so that students feel comfortable about changing their mind is a big concern, since in school being "wrong" is traditionally something to hide or to be ashamed of.

He explains, "Because it's three-fourths, that's what I said, it's three-fourths; so three crayons is a fourth, so three, and that's a fourth, that's a fourth, and that's a fourth, so that's three-fourths."

Should I say something here? Many teachers would praise him for his explanation and for figuring out and revising his answer. I would like, though, for the students to come to rely less on me for confirmation and more on themselves.

Riba, waving her hand, disagrees. She says that one-fourth should have four crayons in the group — like Sean had presented it at first. "This is what I think: three-fourths is like, um, three groups of four."

Should I ask Riba to say first what she thinks of Sean's explanation, partly to help her learn what it means to show respect for his ideas and partly to make sure she has really understoodwhat he was saying?

I ask for other students' reactions. Ofala says she agrees with Sean. "I think he's right because he's taking the three, like separating the three groups plus the one group he didn't circle."

The teacher's role in orchestrating discussions is so hard! Should I clarify what the "4" means in "3/4," or should I let the other students say what they think?

(Continued on the next page)

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ideas? How are disagreements expressed and handled? How much risk is involved in being wrong? To what extent can every student participate and learn in the class?

Our Professional Discourse as Teachers

Working to become as skillful as possible in our classrooms requires us to learn to see more and more broadly and deeply. We must examine the language of our work with students, reflect on the direction and tone of class discussions, consider the time we allow students to explore and investigate — all these endeavors are critical in achieving the discourse we foster. Facilitating worthwhile learning seems very much a matter of orchestration — of eliciting and interweaving multiple voices, threads, themes, and tones. Examining alternate perspectives on the intellectual and social classroom environment can enhance the virtuosity of our work. This is no easy task.

Perhaps the most valuable part of my experience working on the *Professional Teaching Standards* was what it contributed to growth in my own teaching. As we debated and wrote, listened to others and revised, I gained new ways of looking at what I was doing as a teacher. Many specific people stand out in my memory. When I think about issues of classroom discourse, I think particularly of Susan Friel. Friel asked me tough questions about the kinds of words I used to help my students learn to argue with one another about mathematics. She made me think hard about how I cast the tone of the discourse in my classroom. Specifically, she made me wonder about how students felt when other students said things like, "I challenge you." Was *challenge* an appropriate word to be using? Did the students sound aggressive? How safe was the environment? Was the attitude I was encouraging somehow less inviting to girls than to boys? Friel's questions made me watch and listen more closely, and I changed some of the ways in which I taught my students to talk with one another about mathematical ideas.

Let me illustrate. In **figure 1** I describe a discussion that took place in my third-grade classroom last year. My purpose is to use the discussion as a context for considering issues central to the shaping

FIGURE 1 (CONTINUED)

(Continued from the previous page)

I probe: "Why does he have three in every group instead of four in every group?"

Here I decided that Riba's idea that 3/4 implies groups of four was worth probing further. Does it make sense to do this here — to open up the discussion to a "wrong" idea when it seems to be moving in a "right" direction?

Sean says that if it was three groups of four, "this should have four in each one, and it would be *sixteen*." (In other words, if three groups of four was the answer to three-fourths, it would have to be three-fourths of sixteen, not of twelve.)

He erases the extra four lines and turns to Riba. Pointing at the drawing, he says, "These aren't fourths, these are thirds because there's three groups and that makes them a third." Keith raises his hand and explains that what Riba is saying is that one-fourth means "one group of four." Riba nods. Sean turns to the class, and the following dialogue ensues:

Sean: Let's take a vote! How many people, um, think that my answer is correct raise their hand, and how many people think Riba's answer is correct raise your hand.

The situation seems to be becoming competitive — a situation in which Riba's ideas are pitted against Sean's and in which one of them will be a "winner." Voting has been a big part of their experience in settling group matters. Yet figuring out what makes sense in this situation does not seem to be a matter of democratic vote. Should I just explain this idea to him? I decide to ask him what he is thinking.

Teacher: Why would that be a good idea? What would that do if we saw that? Why would we want to know that?

Sean: That would prove it.

What is Sean's notion of what makes something right or true in mathematics?

Students: No! No!

Teacher: Keith, you're shaking your head. Why wouldn't that prove it?

Keith: Just because, like, just because somebody agrees with another person doesn't mean that they're right.

Betsy: I have an example of why voting doesn't work. When we were talking about zero, if it was an odd or even, a whole lot of people said that it was an odd; but then afterward we figured out that it was even, and voting didn't help us know if it was odd or even because the answer was opposite than what people had voted.

This seems to be a good example from their shared experience that may help the students understand why knowledge isn't simply legislated.

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of the discourse within the classroom and to offer an example of the kind of discourse about teaching that I think the *Professional Teaching Standards* can promote. I am not telling this story to set myself up as an exemplar of "good teaching." Quite the contrary. The snippet is in many ways quite ordinary, and it brings up tough questions that we all face many times a day. As you read, consider what is going on, consider my comments and questions tomyself, and consider the issues you would take into account in orchestrating this lesson yourself.

My commentary on the lesson segment is of course incomplete. I did not raise all possible considerations nor reflect on all the things that were on my mind. I did not include others in this particular conversation with myself. Readers who examine with me this excerpt from my teaching will notice different things than I did. They will have different concerns and questions. No single issue is the essential one; none is definitively inappropriate. The traditional isolationist culture in teaching — that everyone has to find his or her own style, that admitting to reaching an impasse or having a hard time is tantamount to an admission of incompetence — has been a crippling aspect of our work as a community of educators. At the same time, although we know better, we seem to talk as though "a right way" exists to motivate students, to teach place value, or to respond to certain kinds of questions from students. On one hand, then, we have pretended that we have nothing to learn from one another. And on the other, we have pretended that teaching is simple and straightforward.

Establishing and maintaining patterns of discourse, fostering the environment of the classroom — these are not matters of right or wrong. But by articulating our thinking and concerns — to ourselves and to others — we can increase our own professional skills. By raising new questions and issues that shape the ways in which we see and think about our classrooms, we can enhance our orchestration of interaction in our classes in ways that can contribute to the kinds of learning outlined in the *Curriculum and Evaluation Standards for School Mathematics* (NCTM 1989). This is the role that I hope the *Professional Teaching Standards* can play — to give us tools for examining and building our teaching as individuals and as a community.

Conversations of this sort — with ourselves and with a wider range of others — can help us as teachers develop our sensitivity to, and repertoire for, structuring the discourse of our classrooms. Although it cannot prescribe what any one of us does

FIGURE 1 (CONTINUED)

(Continued from the previous page)

Teacher: So how did we change our minds, then, if the voting doesn't work?

Betsy: Because the people found out patterns and the number line and they figured out that no, zero must not be an odd because when it goes up there it goes odd, even, odd, even, odd, even; and so when you had an odd number like one and then you have zero, zero must be even because that's the way it is.

Teacher: Anybody else want to comment on this before we go back to our problem of fourths and thirds? Mei?

Mei: I don't think it would work, but it would be fun to see how many people agree with him because maybe some people would come up with some other idea.

With a sudden start I recall how often I have "polled" the class — not to settle matters of disagreement but to give myself and the students some information about the distribution of ideas in the group. I do not think of this approach as "voting" — that is, as a means to determine the correct answer. But this distinction is subtle, and I do not know what the students may be thinking about the role of voting.

Teacher: So, you'd be curious just to know what people are thinking?

Mei: Yeah

Sean: I agree. But that's a really hard question that Riba is asking, but why shouldn't there be four groups of, um, three.

I suggest that we return to trying to interpret what three-fourths might mean. Betsy volunteers that she has an idea.

Why is Betsy doing so much of the talking today? Should I do something here to elicit the ideas of other students, or should I call on her and see what she says and then go from there? It seems that on different days, different students are more active than others. I am never sure how much to press on this — I do understand that students can be very engaged without speaking. Still, a big issue is how to keep an accurate sense of who is tuned into what and what patterns emerge across days. I want to encourage different students to participate and to be as thoughtful as possible about offering varied opportunities for participation.

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FIGURE 1 (CONTINUED).

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Betsy: I'm thinking about what's a fraction that you know is true. A fraction that you know, that we already agreed . . . just wait. . . . *(pauses, thinking of an example)* Okay, yesterday people agreed on half of twenty-four was twelve, right? *(to Riba)* Do you agree with that? Half of twenty-four is twelve? Well, if we put twenty-four lines, we don't circle *two* in each group, do we? We went, "One, two, three, four, five, six, seven, eight, nine, ten, eleven, twelve." Then we cut it right there and we circled this half, and that would be half.

See, we have, we have *two* groups here, right? This (pointing to the "2" in "1/2") means the groups.

Betsy has connected the question of what the "4" means in "3/4" to what the "2" seems to represent in the more familiar "1/2." It is noteworthy to me that she is trying to convince Riba and the other students on the basis of something that she says they "already agreed" on. So now what? Should I get more students to respond to this question? Should I poll the class to see if some consensus is reached on this idea? Could I help the students understand the difference between taking a poll in a discussion and making a decision about an idea on the basis of a vote? Should I take the opportunity to amplify what she is saying and underscore her point — thereby indicating that it is right (given a part-whole interpretation of fractions)?

from moment to moment in our classrooms, the *Professional Teaching Standards* can provoke us to work alone and with one another in ways that we have not typically done. We could learn to talk reflectively and analytically about what we do and what we think and about the struggles and dilemmas with which we contend on a daily basis. To make this change will require some substantial changes in our professional discourse — in what we talk about with one another and in what ways. Such change requires us to rethink our assumptions about what counts as evidence for believing or doing something in teaching and to let one another behind the proverbial classroom door — to explore one another's practices, to raise hard questions, to help one another grow.

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National Council of Teachers of Mathematics, Commission on Standards for School Mathematics. *Curriculum and Evaluation Standards for School Mathematics.* Reston, Va.: The Council, 1989.

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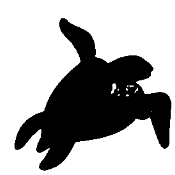
Articles 9 & 10

What Is Science?

Science Talks: An Overview



Articles 9 & 10

ARTICLE 9: What is Science?

Gallas, K. (1995). *Talking Their Way Into Science*. 7-16. New York, NY: Teachers College Press.

ARTICLE 10: Science Talks: An Overview

Gallas, K. (1995). *Talking Their Way Into Science*. 17-31. New York, NY: Teachers College Press.

Gallas begins the first chapter by presenting a view of science in contrast to the standard textbook view. In her view, science is dynamic and changeable, relies on talk, intuition and imagination, and is affected by the subjective lens through which scientists view their work, rather than a static discipline pursued by objective scientists discovering facts. She writes about her own vexed relationship to science as a learner, and how she wanted to make science more accessible to her students. In the second chapter, Gallas describes her discovery that the most exciting talk about scientific ideas among her students came about informally outside of her teaching role. Building on this discovery, she introduced "Science Talks" into her first grade classroom, a particular kind of discussion in which students freely and imaginatively discuss their own questions. She discusses how students participate in science talks and what she and her students learn from them.

Questions

- What is Gallas' view of science ? How does it fit with your own?
- How does Gallas view her own relationship to science? How would you describe your own relationship to science (and to math), both as a learner and as a teacher?
- How does Gallas describe the shift in her science teaching practice? To what does she attribute this shift?

- Gallas describes an activity that emerged in her classroom which she calls "Science Talks." How are they structured? What is Gallas' role in them? What does Gallas believe Science Talks are useful for? What, if anything, do you think Gallas' students are learning in their Science Talks? Is there anything "scientific" about what they are doing or saying? Do you see ways in which their everyday experience of the world is a resource in their thinking and talk?

- What similarities and differences do you see among Gallas' practice of Science Talks and the modes of talk in science and mathematics discussed in other papers (e.g. Ball; Ballenger, Rosebery et al., Brenner)?

- Have you ever tried anything similar to Science Talks? If so, what was your experience with them? If not, what role, if any, do you think Science Talks might play in your own practice?

What Is Science?

> The purpose of scientific enquiry is not to compile an inventory of factual information, nor to build up a totalitarian world picture of Natural Laws in which every event that is not compulsory is forbidden. We should think of it rather as a logically articulated structure of justifiable beliefs about nature. It begins as a story about a Possible World—a story which we invent and criticize and modify as we go along, so that it ends by being, as nearly as we can make it, a story about real life. (Medawar, 1982, pp. 110–111)

Considered from the standpoint of most teachers and students, we know that science is an intimidating and difficult subject. It presents a serious dilemma for all those who want to participate in it, and that is that as it evolves over years of schooling it often becomes a rigid, prescripted process where formula, rather than thinking, is valued. In schools science is represented as a particular kind of exclusive discourse that one must master, a dispassionate discourse that relies on special structures: on hypotheses, experimentation, the identification of variables, replication, logic, the understanding of paradigms, and above all an attitude of certainty. Most students of science never learn to use this discourse very well, and most teachers are intimidated by it. As a result, science is seen as a field for the talented few, and the achievement of real scientific literacy in this country is the exception, rather than the norm.

It is clear to me in thinking and reading about science that the way it is presented in most schools is a poor imitation of what practical science can be in the real world. What I experienced as a student, and what most teachers and students view as science, is an archaic model that emerged in the late nineteenth century (DeBoer, 1991). Despite periods of educational innovation in the twentieth century, this model has not grown to include the questions and the knowledge of the twentieth century: questions about the practice and authority of scientific knowledge and about the purpose of science education in a democratic society; new understandings of human development and the growth of intelligence, of the links between creativity and scientific achievement; and revisions in our views of what the "scientific method" really is (Duschl, 1990; Lemke, 1990; Medawar, 1982; Storey & Carter, 1992). What science teaching does reflect, however, is the separation that has gradually taken place between the world of the scientist and the reality of the lay public.

Certainly the language of science has become more narrowly defined and more exclusive. As I have pointed out, much of the teaching of science in my childhood was based on acquiring the "appropriate" language, on understanding the scientific method, on learning the proper procedures, on precision in measurement and reporting, and, as a result of these rigorous processes, on identifying who was scientific and who was not.

In reality, of course, science is not so neat and clean, and future scientists are not so handily identified. Like teaching and all dynamic and changeable professions, science is a creative and exploratory field that draws upon many kinds of knowledge. Yet in the process of translating a field of *practice* into the *study* of a field, the essence of the practice is lost, and the human resources that will fuel the development of the field are discouraged.

My classroom is filled with the "stuff" of natural and physical science. There are a variety of animals living in different habitats: a rabbit who hops around on a tether; salamanders, snails, slugs, and a variety of insects in a terrarium; a fresh water aquarium with fish, plants, snails, newts, and insect larvae; a pair of cockatiels that mate and raise babies in the spring; an exploratory table with rocks, shells, nests, and assorted other treasures from the natural world; changing centers on magnets, pulleys, the human body, dinosaurs, volcanoes, and so forth. These materials are the backbone of our science curriculum. They enrich it by providing ongoing experience with concepts such as habitats, animal families, and adaptation, to name a few, and they provide us with focal points for units of study, for example, on motion and speed. Further, they often stimulate the children to ask questions that we go on to discuss in Science Talks, and we return to them again and again as we search for answers to our questions.

I have provisioned my classroom this way because of my own strong interest in developing a rich science environment, an interest that has developed over time as I have begun to follow my instincts about those things that fascinate children. (I could say that I've begun to retrieve or discover my own fascinations, and that also would be accurate.) However, I was not a science major in college, and I do not have any special training in a particular field of science. Nor did I have much success as a student of science in high school and college. I have never had a course in the methods of teaching science, and when I examine why science is so central to my classroom I have to conclude that on some level I am filling in the gaps of my own education. In the process of teaching young children, I have rediscovered, through them, the joy and wonder that the natural world provokes. It is a response that celebrates the attitude of *not* knowing and wanting to find out; that requires that all questions be asked unself-consciously. And it is contagious.

WHY TALK?

> Any language taught only by adults to adults—or to children as if they were adults—becomes in certain respects "dead". It fails to enlist recruits, it may lose its productivity, and it serves in the end primarily to separate those who know it from those who do not. (Mead, 1959, pp. 143–144)

There is a distinction that must be drawn between a science environment that incorporates child-centered, hands-on methodology, but considers primarily the teacher's questions, and a classroom in which knowledge about science and the world is carefully *co*-constructed, incorporating a child-centered, hands-on methodology that is framed by children's questions. The former represents my work as a science teacher before I began to examine the link between talk and the language of science. Children in my classroom, prior to my work on talk, had varied and rich explorations in science, explorations that I would orchestrate as I provisioned my classroom and encouraged exploratory action and talk focusing on my predetermined questions and assigned tasks.

My goal was to offer them many opportunities to be deeply involved in the stuff of science, to fully explore and act upon those materials while also posing questions that I thought would provoke growth in their thinking. In effect I was always prodding their thinking to go further. Often, however, I was prodding without a clear sense of where "further" was for the children. I knew where I thought their thinking was going, but my ability to assess the real path of that thinking was limited by my own conceptualization of how to direct and guide it. While my students did, in fact, richly construct new understandings of their world, *I did not always richly construct what their understandings were.*

At some point I began to wonder what children thought about subjects that were not considered to be developmentally appropriate for them. I would eavesdrop on their informal conversations about the universe, about electricity, about the onset of winter, about aging; and I realized that those kinds of topics were missing from my curriculum, but were of deep and intense concern to my students. I perceived that in spite of my prodding, I was not always challenging the children's potential as *thinkers* and their natural ability to consider complex and difficult questions in ways that were useful to them. *I* had always been in charge of the questions, asking them and often answering them, and deciding which of the children's questions should be heard.

Looking More Closely at Language

> The more a learner controls his own language strategies and the more he is enabled to think aloud, the more he can take responsibility for formulating explanatory hypotheses and evaluating them. (Barnes, 1976, p. 29)

Thus, when I began to pursue research on language and literacy, my interest turned to using talk to better understand children's thinking about the world. I was very committed to having children "think out loud" and initiated Science Talks as a way to gather data on the children's questions and their ways of talking about science. Gradually I came in contact with some of the research on classroom discourse (Cazden, 1988; Gee, 1990), on collaborative talk (Barnes, 1976), on narrative (Bruner, 1986; Cazden, John, & Hymes, 1972; Hymes & Cazden, 1980; Wells, 1986). Those works expanded my understanding of talk and fueled a philosophical commitment to it that transformed my practice and re-oriented it.

I learned that what my children were doing as they took over the Science Talks was qualitatively different from what I had orchestrated before the talks. Much to my discomfort I also learned that there was a subtle difference between a child-centered, developmental classroom, where teacher and children construct (usually in a carefully controlled way) knowledge about the world, and a classroom where that process continues but a focus on discourse is added.

In the former classroom, the teacher is in charge of what is said about a subject. The children's remarks are filtered through the teacher's mouth, usually in the form of revoicing and questioning. If there is discussion, the teacher orchestrates it, choosing who talks, what is said, and the most important ideas to be considered and pursued. As Edwards and Mercer (1987) point out, often the most developmentally oriented teaching subtly controls what is said and done, maintaining a basic "power asymmetry" in the classroom. Even in very active learning situations, the notion that students work with their own ideas is "illusory" (pp. 156–158).

Co-Construction of Learning

In a classroom where the appropriation of many different discourses is the goal, the children co-construct, or build together, ideas about seminal questions through real dialogue, and the teacher listens and reflects without immediately agonizing over what *ought* to be said. Instead of intervening in children's discussions at "teachable" moments when children are stating disturbing misconceptions, the teacher begins to focus on issues of language and culture, and wonders how to bridge the gap between her intentions and the child's life experience. Explorations with materials and ideas continue, the commitment to hands-on learning remains, but the teacher's understanding of what she *does not know* about her children rises to the forefront.

I became more and more interested in uncovering children's understandings, and as I did so I realized that too many children brought little or no personal experience to the study of science. While they all had a natural curiosity and interest, few of them understood how the subject fit into their lives. Science was for school, and I (ironically) was the only "scientist" they knew. My sense of responsibility for helping my students place science into the immediate context of their lives grew as I realized that the only way to do that was to uncover their "Stories About Science" (Gallas, 1994), to elicit in any way possible their theories about difficult questions, and to draw very clear connections between their present and future lives and the study of science in school.

As I learned more about language, "co-construction" (Barnes, 1976) was a term that began to fascinate me and showed great potential for children. I had seen how children, when given the opportunity, could use the process of discussion to explore their ideas and construct new ones together. On the one hand, the concept of co-construction was closely related to what I had been doing as a developmental teacher, except that I had been in charge of the "co" part of the co-construction. Although I had been focused on developing children's ideas and encouraging their ability to communicate those ideas, I agonized when they consistently would present me with incorrect and bizarre explanations for what they were observing. How could I guide them toward more "correct" conclusions without violating their sense of control over the process of learning?

A closer examination of what happened when children were allowed to collaborate in their thinking without my interference showed me that the process of collaboration had great potential to teach *me* about children's thinking. When I was finally able to be quiet in Science Talks and my students really began to co-construct their ideas together, the outcome was fascinating (see Gallas, 1994). It was as if the eavesdropping I spoke of earlier became formalized, and I could view how their ideas developed, watch theories being built, and be amazed at the power of a group of children thinking together. As time passed (and later chapters will describe), I could even witness where my own teaching had or hadn't been effective.

WHAT IS THE DISCOURSE OF SCIENCE?

> Our discussion is informed by the conviction that a body of practices widely regarded by outsiders as well organized, logical and coherent, in fact consists of a disordered array of observations with which scientists struggle to produce order. Despite participants' well-ordered reconstructions and rationalizations, actual scientific practice entails the confrontations and negotiation of utter confusion. (Latour & Woolgar, 1979, p. 36)

> Ask a scientist what he conceives the scientific method to be and he will adopt an expression that is at once solemn and shifty-eyed: solemn, because he feels he ought to declare an opinion; shifty-eyed because he is wondering how to conceal the fact that he has no opinion to declare. (Medawar, 1982, p. 80)

> Physicists do not start from hypotheses; they start from data. By the time a law has been fixed into an H-D (hypothetico-deductive) system, really original physical thinking is over. (Hanson, 1965, p. 70)

> It is not easy to be sure whether the crucial idea is really one's own or has been unconsciously assimilated in talks with others. (Sir Lawrence Bragg, 1968, p. viii)

> As Einstein himself once said, he succeeded in good part because he kept asking himself questions concerning space and time which only children wonder about. (Holton, 1978, p. 279)

> Things are much more marvelous than the scientific method allows us to conceive.... *Why* do you know? Why were you so sure of something when you couldn't tell anyone else? You weren't sure in a boastful way; you were sure in what I call a completely internal way.... What you had to do was put it in their frame. So you work with so-called scientific methods to put it into their frame *after* you know. (Barbara McClintock, in Fox-Keller, 1983, p. 203)

What I have found out since I began documenting Science Talks is that the kinds of talk and thinking that children engage in when studying science naturally parallel what both practicing scientists and historians of science report. Children come to school fully prepared to engage in scientific activity, and the school, not recognizing the real nature of scientific thinking and discovery, directs its efforts toward training those natural abilities out of the children. I believe that this process occurs because teachers like myself have never fully experienced or understood what real science is. We have been trained to teach a curriculum without fully exploring both the history of science and the nature of science discourse. Thus our practice as teachers reflects our own flawed education as students of science.

The Process of Science

When I set out to find out what "real" science was, I was fascinated to discover the reasons why I had been so ignorant of the scientific process. Many scientists and historians of science describe how the process of science is completely obscured by the ways in which scientific discoveries are made public. In fact, public impressions of the "scientific method," the isolation of the scientist in his or her laboratory, and the rational nature of scientific discovery are clearly debunked by the accounts of practicing scientists who are willing to discuss their process, by ethnographic studies of laboratory life, and by historical analyses of important work (Beveridge, 1950; Hanson, 1965; Holton, 1973, 1978; Kuhn, 1970; Latour, 1987; Latour & Woolgar, 1979; Lynch, 1985; Medawar, 1982; Watson, 1968).

The Role of Talk

I have learned that the process of scientific discovery is deeply connected to conversation with colleagues, activities that take place both in and out of the laboratory (Latour & Woolgar, 1979; Lynch, 1985). A scientific idea is often the result of many interpersonal exchanges, of interactions with materials, and of false starts. In the end, "facts are socially constructed" (Latour & Woolgar, pp. 169–170). (For an autobiographical account of the pervasiveness of talk in the development of an important scientific discovery, see Watson, 1968.)

Intuition and Imagination

I have also confirmed my long held conviction that the process of scientific discovery is firmly rooted in intuition and imagination (Gallas, 1994). Many accounts of the life work of important scientists confirm that scientists move from a state of deep involvement in the sensation and perception of the unusual in nature toward an articulation of those perceptions. Their initial fascination with a problem originates in childhood wonder and does not proceed toward resolution in a purely logical fashion, but rather combines the processes of creative and critical thinking to produce advances in both the development of theories and the solutions to problems. As Einstein stated: "To these elementary laws there leads no logical path, but only intuition, supported by being sympathetically in touch with experience" (quoted in Holton, 1973, p. 357; see also Cobb, 1994; Fox-Keller, 1983; Hanson, 1965; Holton, 1978; Rothenberg, 1979).

Early Childhood Experiences

Some historians of science have suggested that important events in early childhood often mark a turning point toward fascination with science. Fox-Keller (1983) describes maize geneticist and Nobel Prize winner Barbara McClintock's childhood as representing a deep immersion in, and fascination with, the world of nature, while Holton (1973) cites Einstein's recollection of his first exposure to a magnetic pocket compass at age 4 or 5—an event that provoked his lifelong interest in the mysteries of physics. Holton (1973) calls this memory "an allegory of the formation of the playground of his [Einstein's] basic imagination" (p. 360). In other words, a love of science and the attraction to particular kinds of problems are potentially set into motion in early childhood.

Philosophy and Metaphysics

These fascinations often emerge early and become closely guarded beliefs and preoccupations that continue for a lifetime (Cobb, 1994; Fox-Keller, 1983; Holton, 1978). Holton labels these "thematics," or an individual's theoretical picture of how the world works, and proposes that they form the underpinnings of all scientific work and can account for the development of different schools of thought in a particular field of study. He notes that in the history of science, there are only a few persistent themata, for example, evolution vs. devolution, reductionism vs. holism, hierarchy vs. unity, chaos out of order vs. order from chaos (p. 10); and he postulates that these may emerge even well before an individual becomes a scientist, "in a part of the imagination" (p. 17). A deeply held belief in one of these themata can determine the direction of a scientist's research as well as his or her interpretation of data.

Subjectivity

> And yet, on looking into the history of science, one is overwhelmed by evidences that all too often there is no regular procedure, no logical system of discovery, no simple, continuous development. The process of discovery has been as varied as the temperament of the scientist. (Holton, 1973, pp. 384–385)

Each scientist brings her or his own very subjective lens through which to examine a question. In fact, the separation of the subjective, personal vision of a scientist and the more objective world of "real" science is not, as some critics of modern science propose, as clear-cut as most of us believe (Edelglass, Maier, Gebert, & Davy, 1992). Because most of our knowledge of science is communicated to us as finished and accepted facts or theories, that is, as "final form presentation of science" (Duschl, 1990, p. 68), we do not have any knowledge of the process of "private science," which is influenced and bounded by social, intellectual, metaphysical, and creative processes that most of us would believe to be quite "unscientific" (Fox-Keller, 1983; Rothenberg, 1979).

Thus, in examining the world of the scientist, I find that the interpersonal—that is, talk and the laboratory—is linked with ideas that emerge from the purely personal playground of imagination and wonder. The very private musing of a child finds its origins in wonder and may eventually be transformed through reflection, dialogue, and finally collaboration into a question and ultimately a theory about the world. These are the seeds that the classroom can nurture and build upon as teachers and children mutually engage in the world of science.

Science Talks: An Overview

VERA: Yeah but my question is . . . why should ice float, if, if water sinks, because ice, ice, you see, if we put some water on a scale, and then ice, what would the water weigh? It would hardly weigh anything, and if we put ice on the scale, it would weigh something. But, but then why would it not, why does water sink and if it doesn't it won't weigh anything? And why would

DANNY: Uh, Vera?

VERA: ice float if it does weigh something?

DANNY: Um. How would we, um,

CHLOE: If you put it in something, then it will make it heavier.

VERA: You could try a scale. Oh, I know, I think I know! Maybe it's the amount of water, maybe it's the amount of water that made it heavier, and, the

DANNY: Vera?

VERA: the ice, the, um, and there was a little bit of ice and there was more water than the ice.

OLLIE: Vera?

VERA: Yeah?

ROBERTO: There is a way. There is a way to weigh water, like Mr. P. said. He took a piece of tape, and he writed it. He made numbers on it so there is a way to weigh water. Vera is right.

ARI: Or you could put it on a scale.

T: Or you could put it on a scale.

VERA: Or you could *pour it* on a scale? Or you could pour, um, a bucket of water onto a scale . . . but I doubt my mom and dad would let me do that.

—Excerpt from the Science Talk: *"Why does ice float?"*—Grade 1

For my class, Science Talks emerged as a type of discussion in the fall of 1989. At that time I initiated the talks in my first grade classroom based on my long-term observations that the most exciting science discussions took place informally, outside of my teaching role. I originally had intended the discussions to be child-centered, with little if any direction from me. What I hoped to discover was the young child's natural style of talking about the world. It was, one might say, a naive and fairly unconstructed piece of research, but it quite adequately represented the style of teacher research that has characterized my practice. What I had was a question and some undocumented knowledge that children were far more sophisticated and able to think about difficult questions than my training in cognitive science had led me to believe. Thus, I began with a question and a hunch, and the style of Science Talks was conceived.

Since the first year of talks in 1989, I have witnessed more than 100 Science Talks with both first and second graders in my own classroom, as well as with classes of third and fifth graders. Those children and other teachers have taught me that the effect of Science Talks is consistent across the grades. For children, there is an immediate sense of the importance of the discussions. When their teachers and I ask them what questions they would like to talk about, and we proceed week by week to set time aside for discussions in which we are not the leaders or the experts, the children begin to work hard at talking to each other, much as the children did in the excerpt that opened this chapter.

For teachers, the talks always provide a surprise. Sometimes, as in this excerpt, what is striking is the tenacity of a child like Vera's effort to talk through an idea. Or it may be the care with which the other children responded to and tried to assist her, or it may be simply taking delight in the unbounded enthusiasm and ingenuousness Vera portrayed when she suggested pouring the water on a scale and then decided, "I doubt my mom and dad would let me do that." On some level, these talks enable teachers to see their students with fresh eyes, to savor their intelligence and deep enthusiasm for a question.

Yet I, and most teachers who have tried this kind of talk, are never prepared for the distress we feel when we find we have to be quiet. It is the teacher's way to want to facilitate discussion; to moderate who talks and for how long; to discourage what I call bird walks, or digressions that seem to be off the topic; to make sure that children finally get the right answer (if it's a known one). When children eagerly begin to co-construct theories, when their exploratory talk wanders so broadly and quickly that we can't follow it, we make an assumption that the talks are out of control.

For many teachers, and this was absolutely true for me, the process of hearing an audiotape of the first talk and realizing how dominant our voices are even when we are trying *not* to control the talks, is daunting. The act of giving up overt control of the talks takes time and determination, and is almost painful. One must trust that the act of talking about a question is an opening for much richer scientific explorations. The reward, however, is the ability to watch and document the natural unfolding of dialogue among children, to see a class of children begin to think in concert, and to witness the power and deep intelligence they have as individuals and as a group.

INTRODUCING THE TALKS

I began our first Science Talk with a focusing question, one that I still use every year with each new class because it illustrates the nature of the questions we will consider. "Why do the leaves change color?" I ask each fall, and just as in the first year I am continuously astonished by the enthusiasm and originality of the children's theories and the eagerness with which they adopt the talks as their own.

"Why do the leaves change color?"—October 1991—Grade 1

TOM: It gets colder and all the green comes out of 'em, and all the brown, it takes all the wh—

?: the juice

TOM: it takes all the juice out of 'em that the caterpillars eat.

T: Oh, so it takes all the juice that the caterpillars eat. . . . You don't think that?

?: Karen, Karen.

T: Go ahead, Ellen. Listen to her and she'll give you an idea.

ELLEN: Because I, I don't think caterpillars could drink that much juice 'cause trees have a lot.

TOM: No, they eat the leaves. And the juice goes into them, and they grow bigger and bigger and get into a cocoon so their skin peels off.

T: You don't agree with that? Why don't you agree with that?

TOM: I don't agree with what she said.

T: She hasn't even said anything. Tom, in Science Talks the purpose is not that each person is the best science talker. The purpose of Science Talks is that you begin to talk *with* your friends and figure it out together.

ELLEN: I don't know . . .

T: What do you think? Everybody may not know.

ELLEN: I think the sap runs out.
T: You think the sap runs out?
ELLEN: Of the leaves. 'Cause it goes, 'cause it goes, 'cause leaves sweat like we do.
T: Yes, leaves sweat like we do. Water comes out of them.

As I noted earlier, I generally introduce Science Talks in early October and describe them to the children as a time when they can speak with each other about important questions. As an introduction, I propose a question that is completely open ended and whose answer will most probably be unknown to children of their age. In the first talk, we sit in a circle together, and I establish one rule: *You don't have to raise your hand*. I need that rule, because it is important that I, as the teacher, am not seen as the moderator of the discussions. I also do two things in the early talks. First, as the above excerpt shows, I try to show how to listen and how to recognize each child who wants to participate. That is both a verbal and and nonverbal kind of modeling. In other words, in the excerpt above I responded to Ellen's remark by saying out loud what I might have said in my head to make sense of her statement.

ELLEN: 'cause leaves sweat like we do.
T: Yes, leaves sweat like we do. Water comes out of them.

And at the same time I acknowledge Ellen's nonverbal response (shaking her head "no") to Tom's early remark by turning my body toward her and urging her to say what she's thinking: "You don't think that?. . . Go ahead. . ."

Sometimes, as with Tom in this discussion, I provide very explicit information about what distinguishes these kinds of talks from other situations: "The purpose is not that each person is the best science talker." I am both coaching him as to what his goals might be for the talk and establishing a protocol. In other words, I am telling Tom not to intimidate other children by being verbally combative, something that characterized much of his interactions in the early part of first grade.

In order to keep track of participation for our follow-up discussion, and for my long-term records, I also tape record the talk (see Appendix B for full transcripts) and take field notes, recording, for example, who spoke; what previous idea, if any, they referred to; explicit examples of silent children whose body language indicated attentiveness to the process; descriptions of the development of theories, and so forth. The following excerpt from my field notes shows the kinds of observations I might make. (Note that brackets indicate my interpretations of different events, or reminders to myself.)

Field Notes: March 23, 1994—*"How do plants grow?"*

> This is a question Cindy has framed to support her unit on growth. Germaine starts out with a very practical statement on how to plant a seed. Maurice repeats it. Michael asks to clarify the question. Dierdre asks a super question in response to Michael's, and it's a beauty! [Check that one out on the tape.] Michael says, "What about the pumpkin seed? It sprouted without dirt in the sink." [Conditions for growth: Evidence from their own experience. Note new talk/science behaviors here: 1. Asking for clarification of their assertions. (See Mia on tape.) 2. Nate asks Tian to "define 'nutrition,'" meaning "define your terms." This is a trend we started with the *Gravity* talk when I asked Michael to define "gravity." 3. Questions are leading to more questions of greater complexity.] Germaine is getting *so* clear in how he forms his questions. He really uses "maybe." This talk keeps going back to the question, "How did plants begin?" Eli tells me that that should have been the "original question." At the end, Germaine says, "I have a question. True or false, do plants grow best in water?" [Wow! Fantastic! He is truly honing in on what this science stuff is!]

In early Science Talks, not all children talk, but there is usually a core who try to say something, a group that is silent, but very attentive, and a small number who are either uncomfortable or feign disinterest. (The latter kinds of children will be discussed later in this chapter.)

The first talk usually lasts about 15–20 minutes and is followed by a brainstorming session of more questions. We also talk briefly about how the talk went, and from my field notes I make very explicit comments about the kinds of things I saw that let me know someone was really listening and thinking about the statements of others: body language, eye contact, references to prior statements, and questioning; for example:

T: There were some really good ideas here. People came up with really good things, and if you were thinking silently in your head, that's fine too, because I know. I could see everybody was think-

> ing and their brains were going. So, for people who spoke and told us your ideas out loud, they were good ones. For people who were thinking, think some more about it. See what you, see what you come up with.

However, I do not establish any firm rules for the talks beyond the "you don't have to raise your hand" rule. Each group and age of science talkers is different, and the kinds of rules and interventions that facilitate the talks differ from class to class (see Chapter 9 for further explanation of the teacher's role as coach and model).

WHO OWNS THE TALKS?

One spring, my student teacher, who was conducting a unit on seeds, scheduled a Science Talk and told the children she wanted them to talk about her question. There was an immediate uproar. "You can't ask a question," a child retorted, "these are our talks!" The student teacher was stunned, but persisted by explaining that she didn't want to take over the talks, only to find out what they thought about her question. The children very graciously relented, but this incident underscored the issue of ownership of this forum.

When I initiated the talks, my intention was to establish a regular structure where the children's ideas and questions would predominate. In the first year, I never proposed a question of my own, but in the spring of that year, I witnessed a talk on the question, "What makes the wind?" which I followed by a read aloud experience from a book of the same name I happened to find. Two weeks later, I followed up with a second talk on the same question to ascertain the impact of the book. Because this question is not one that is normally considered in a first grade science curriculum, it was an unusual opportunity to see whether changes had taken place in the children's thinking as a result of the original discussion and the reading of the book. Within this second discussion I observed that not only had every child understood how wind was made, but they were able to move beyond the original question to consider two more difficult ideas: how tornadoes are made, and how air circulation affects weather patterns.

It was clear to me that the first discussion had focused the children's thinking on the question and had created a readiness for new information. I saw at that point that the Science Talks could provide a powerful tool for me to use as a teacher. The following year I began to judiciously insert questions of my own at times when we were about to begin a unit of study. I have found that a discussion of my question prior to a unit of study prepares the children for consideration of new ideas. It also enables me to assess the kinds of knowledge they bring to their work. (Chapters 5, 6, and 8 will expand on consideration of both the importance of identifying seminal questions prior to a unit of study, and how children's misconceptions are revealed through the talks.)

In this way the ownership of the talks expanded. My students are now much more comfortable with my occasional use of the talks for my own purposes. However, there is a further issue of ownership that relates to participation by the children. Science Talks enable new voices to emerge as authoritative because the hierarchy of the classroom is blurred when the teacher moves out of an authoritative role. I have found as I have worked with my own classes and with other teachers that the open ended format of the talks allows children who are not high achievers to show that they are keen observers of the world and powerful creative thinkers. In effect, the Science Talks, by considering questions whose answers are not known, invite every child to participate. The process of constructing an answer with others, of using everything that's been observed and imagined, stimulates more participation in science than a recitation of information from a book.

I also am often surprised at the long periods of silence maintained by those children who are not able to participate in the talks. Obviously, some of those children are inordinately shy and need a very long time to truly believe that every idea will be thoughtfully considered. My active presence as a listener and archivist guarantees that each child will be respectfully heard, although some classes need quite pointed work in how to listen to others. (Chapter 9 will discuss that kind of challenge in more depth.) Shy children, however, are usually very present as listeners, following the discussions carefully with many nonverbal signs of participation and interest. Eventually, most of them do attempt to participate.

In my experience, however, the most striking nonparticipants are the children who one would most expect to delight in these talks, and those are the high achieving, highly verbal, information-oriented children (usually boys), who normally stand out in teacher-led discussions and in child-centered explorations of materials.

Donald is that kind of child. He entered school with an extraordinary amount of memorized book knowledge about science. He had the kind of information about space, animals, and plants that normally astonishes adults and leads them to pronounce that such a child is gifted and precocious for his years. Soon after entering school, Donald was recognized by his first grade class as the science expert. His love of the natural world, his library of books, and his accounts of family excursions on weekends provided rich information for us all.

However, I soon observed in my field notes that in first grade Donald rarely participated in Science Talks. He would remain silent during the talks, and, further, he was inattentive to the other children's ideas, trying to engage his friends in whispering and pranks while they were listening, and very clearly indicating with his body language that he didn't want to participate. When I noticed this, I began to ask Donald outside of the talks why he was quiet. Did he know the answers to the questions? He said that he didn't know the answers either, but that he just couldn't think what to say.

His silence continued throughout the year, with a few exceptions of talks in which he had some information. I noted in my field notes in late March, during a talk on "What makes colors in nature?":

> This is a very raucous discussion. I notice that all the children are participating except for Donald, our most knowledgeable science buff. I realize that he never speaks in a Science Talk unless he has had prior information on the topic. He is unable to engage on this one. I wonder if too much prior knowledge makes you less able to work on open ended questions. In some ways these talks make a level playing field. All children can participate and build plausible theories.

Later in April, my notes record this observation during the talk, *"Does the universe end?"*

> Donald entered this discussion first to clarify the question and then to make an extensive display of knowledge. He spoke in very quick spurts, like he was reading from a book, kind of a staccato delivery of facts, "'cause the sun'll burn, and the sun will be a white dwarf, 'cause the sun's a star, and then, um, the earth'll burn, and we'll freeze." Later in the talk, Donald forcefully rebutted Katie's mix-up of the words "universe" and "solar system." His vocal intonation was very high pitched, authoritative, and impatient: "The universe is the whole space. The solar system, the milky way, our solar system and there's other solar systems to other planets. . . . First of all, there's not only one solar sys-

> tem, and second of all, the solar system is in the universe, so how can it be bigger than the universe?"

The pattern that seemed to be emerging that first year, was that Donald would participate only when there was no risk in joining us because he could display his knowledge, and when he did say something the tone of his remarks was always intimidating.

His pattern is one that I've observed in a few other boys who also hold back from participating in the talks. Perhaps the talks violate their sense of what science is. In other words, they have been prepared before entering school to feel "scientific." For them, science is like saving money in a bank: Acquire an extraordinary amount of information, and that makes you scientific. However, Science Talks, as I noted in my field notes, create a level playing field. Everyone can be scientific, even the least privileged children in the class, and everyone has important questions that provoke energetic discussion.

ABOUT THE QUESTIONS

> True dialogue occurs when teachers ask questions to which they do not presume to already know the correct answer. (Lemke, 1990, p. 55)

The questions that work best for Science Talks, whether posed by teachers or children, are those that are open ended with the possibility of many answers. Initially, some children ask questions that have a very specific answer, for example, "Who made the first clock?" Based on my experience with other classes and other teachers, I have two frames of thought on whether this kind of question should be discussed. Clearly, if this discussion is held, the children soon find that first there is only one answer and if one of them knows it the discussion quickly ends, and second if no one knows the answer the discussion turns into an argument about whether it is possible to determine a correct answer. For some classes of children, particularly in the older grades, teachers have found that it is instructive to let them try that kind of talk, and then discuss what kinds of questions are most useful for developing dialogue. My experience with younger children is that they don't ask as many closed questions, and when they do, it is not always helpful to discuss the questions and why they don't work.

Recently, in working with a class of children that had trouble talking together (see Chapter 9), I learned that questions need to be carefully phrased so that all children are able to understand the context of the discussion. In other words, if a child asks, "What is gravity?" only those children who are familiar with the term "gravity" can speak about the question. (And often, an ability to refer to the word does not imply an understanding of it.) However, there are ways to rephrase the question so that all children can participate in a discussion about the effects of gravity. For example, that question could be rephrased, "Why, when we throw a ball up in the air, does it come back down?" Sometimes what we interpret as uninterested silence, or lack of information on the part of a nonparticipating child, is really a misunderstanding of a question. When the question is rephrased, many children will exclaim, "So that's what you meant!"

Most children, however, ask questions that are simply phrased and either are based on observations of a natural phenomenon or are "big picture" questions. For example, after feeding our cockatiels sunflower seeds each day for more than 6 months, Andy asked the question, "Why don't birds have teeth?" based on his close observation of how the cockatiels cracked and then ate the seeds. That question provoked a rich Science Talk in which the children used very detailed observations of our birds and of other birds they had noticed in nature as well as book knowledge to construct, not an answer to the question, but a theory as to *how* birds ate without teeth. The "why" of Andy's question was saved for a later talk, after we had done further research and observation on the "how." Yet his question was posed in a very practical way that all children would want to discuss, and it prompted a series of rich inquiries by the class.

Another child, in studying birds, might ask a big picture question about birds, for example, "How did birds begin?" That question, although a difficult and confounding one, is one that many children ask as they watch birds in nature or in captivity and wonder about their evolution. In both cases the questions are worded simply and directly, and in tracking children's questions, I have learned to consider how I phrase questions for my teaching, monitoring both the simplicity of the question and the kinds of language I use.

VIEWING CHILDREN'S KNOWLEDGE

> Making explicit the arguments underlying conceptual ambitions and dissatisfactions, . . . we bring to light . . . the particular picture of human beings as active intelligences. (Toulmin, 1972, p. 3)

Toulmin, in describing what he terms an "epistemic self-portrait," proposes that human knowledge must be considered from two vantage points: We need to understand what we believe in, and then we need to analyze the bases on which we anchor those beliefs. The process of Science Talks enables children and their teachers to see each child's epistemic self-portrait and then to pursue the origins and reasoning that support his or her position.

For example, Ellen and Tom have two very similar explanations for why the leaves turn colors. Tom believes, "It gets colder and all the green comes out of 'em. . . . It takes all the juice that the caterpillars eat." Ellen thinks, "The sap runs out. . . . Of the leaves . . . 'cause leaves sweat like we do." Their beliefs are similar, but based on different observations. Tom relates the change to a change in weather and the activity of caterpillars, while Ellen makes an analogy between our sweat and the respiration of leaves. Both children have observed the process and combined that observation with their respective knowledge of nature. Tom, an avid naturalist who specializes in collecting and caring for little creatures such as caterpillars, constructs a theory based on his knowledge of those larvae. Ellen, who is more bookish and a precocious reader, juxtaposes her book facts with her observations of her own loss of fluids and constructs a theory that is similar to Tom's, but distinctly different in its point of origin. Both children enable me to view the origin and structure of their ideas, and to shape my teaching response accordingly.

However, in addition to discovering each child's system of reasoning, Science Talks also enable me to observe children employing overarching beliefs as a basis for building their arguments, what Holton (1978) termed "themata" in his study of the history of science. Over the course of a year particular children might base most of their theories about a variety of questions on one pervasive idea. For example, a child who believes that the origin of all natural phenomena is found in one source, might cite "germs" or "chemicals" as causal agents for almost every seminal event in the earth's natural history from the beginning of the earth to the development of grasses. Other children might believe that the universe is random and disorderly, and therefore that events of any kind are not predictable. Still others believe the universe is supremely ordered and all events are interrelated.

The children who speak in this book often display this characteristic, which Holton describes as consistent in the work of most scientists. Borrowing from Holton's (1978) schemata for how thematics work in the scientific mind (p. 8), experiences that children have in nature enable them to develop propositions about how nature works. Those ex-

Figure 2.1 Two Theories About Why Leaves Turn Color

Tom's Thema
Nature is a balanced system.

Experiences ← → **Propositions**

"It gets colder"; "the green comes out of 'em."

"Caterpillars eat [the juice] and get into a cocoon"; therefore caterpillars are responsible.

Ellen's Thema
There are patterns in nature.

Experiences ← → **Proposition**

"Leaves sweat"; people sweat.

"The sap runs out 'cause leaves sweat like we do."

periences and propositions, however, are mediated by the child's beliefs and convictions about the world. Using this structure, I might picture Tom's and Ellen's themata about this question as shown in Figure 2.1.

If I view a child's theory, or epistemic self-portrait, from this position, I can see that the immediate statement the child makes about nature begins with observations or book facts and proceeds toward the statement of a proposition or theory. Running through that seemingly logical progression, however, and influencing it at all stages, are the underlying themata that Holton would maintain are the underpinnings that determine both the form and the content of most scientific theories. These ideas spring from the realm of imagination, intuition, and metaphysics, and are governed by deeply held beliefs about the world.

By examining the structure of children's thinking in Science Talks, I can trace the logic and consistency of their ideas, rather than focusing on their *incorrect* information or concepts. Further, when children put their ideas out on the floor as part of our discussion, they are showing a willingness to have those ideas discussed, and perhaps modified, if they are incorrect.

Alan, for example, after watching an annular eclipse out on the school lawn for more than 2 hours, developed a magical theory about why the eclipse occurred. The following Science Talk about the question, "Why did the eclipse happen?" took place the next day:

ALAN: Well, I think that, um, uh, the eclipse happens. But maybe it happens every few times. I'm not sure, but maybe it did something to the earth. And the eclipse makes *it* come, and then it wears away. The next, whatever, 14 years, it comes back, to, um, the things come back so it won't go away completely.

Maurice tried to help Alan clarify his statement.

MAURICE: Do you mean there's a . . . plants are starting to get too hot, and then the eclipse comes back, and they cool down?
ALAN: Maybe it's a sign for something.

As the children worked with Alan to help him say more, I realized that he had developed a very elaborate, imaginative, and deeply personal explanation for the phenomenon of the eclipse: The eclipse happened in response to a need from the earth. In Alan's mind, the earth told the sun that it needed something, and the eclipse was the result.

Thus, in the process of talking science, as the child describes his or her beliefs behind a theory, considers new ideas, and has old ones challenged, both child and teacher can see a more complete epistemic self-portrait. Until children's ideas are publicly articulated, neither teacher nor child can consider their meaning and validity. Once ideas have been stated, both child and teacher know where to begin their dialogue about a question, and the teacher can develop experiences that help the child think further about a question. (Chapters 4 and 6 will examine the issue of epistemics and themata further.)

LEARNING TO TALK TOGETHER

VERA: Well, Anita hasn't got the point, I think, because if ice was colder than water, what does that have to do with making it float?
ANITA: But it's not freezing when it's colder when you hold it in your hand.
VERA: Yeah, but what does that have . . . you know. . . . Well then, why do we have, then why, that has nothing to do with what we're talking about 'cause why, if this ice was cold, why would that make it float, even if, why, what does that make, why would that make it float if it was, just if it was, if it was cold, what does that make it float? What does that make, what does that have to do with making it float? I don't understand.
T: Coldness?
CHLOE: Al, what does it have to do with being both tasting good?

ROBERTO: Um, Vera? One more thing. Bet my sister could figure this out.
VERA: Um, Roberto, please!
DAN: This has nothing to do with . . .
OLLIE: We're not talking about your sister, Roberto.
VERA: This is a, this is a 1-G [name of our class] science thing. Now let's get back to what we were talking about. Now Roberto,
ROBERTO: My sister *can* find it out because she goes to science practice.
DAN: Roberto . . . This is nothing about . . . this is nothing about your sister, Roberto.
ROBERTO: And, but it is science, and she knows about science. She can actually figure this out. If I *had* her.
T: Well maybe you could go ask her. Go ask her. Next time you see her, Roberto, go ask her for us.
DAN: He'll see her coming, coming to pick him up, I bet.
JOHN: And then, just, bring her the paper out, and tell her to write it down, 'cause you can't remember it.

During the year, a class of children grows in its ability to talk together and build acceptable theories. If Science Talks are held regularly, once every 1 or 2 weeks, ways of co-constructing knowledge spill over into other areas of the curriculum, and the sophistication of all classroom discussions increases. Further, as a teacher who had to learn to be quiet in Science Talks, my ability to listen and understand children's utterances improves over time.

As the talks progress, I continue to coach the children on ways to make their talks more effective: how to use each other's ideas and support new theories, how to ask clarifying questions and apply prior knowledge. Often there are children in the class who do this naturally. One might say that their dialogic intelligence is already well developed, and they very consciously help discussions move forward. But essentially Science Talks become an invaluable tool for all of us to learn how to discuss and think together.

For myself, the talks open a window into the children's thinking from which I can see their early ideas on many topics, as well as providing me with a view of their deep interests and topics I can pursue in my science curriculum. Often, in the midst of a unit of study, a child will pose a new question that propels our work forward to new and unexpected levels and refines our dialogue about a subject. Thus, Science Talks become a forum where children can introduce new tangents of thought into our ongoing science curriculum. The children seem to that public questions and statements become food for thought for everyone in the class and that one person's question can become everyone's burning fascination. The talks support their growing sense of what science is, of what kinds of ideas science considers, and of how it feels to speak with authority and seriousness about difficult questions.

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EFF-089 (3/2000)