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ABSTRACT

The distinction between the participant and spectator functions of language are used to describe the teaching skills of a fourth grade teacher during a unit of instruction. This study documented the science instruction of a teacher who 20 years ago majored in teaching reading. In recent years she has taken steps to develop skill and knowledge in science and mathematics education. This study focused on the planning and execution of a 31-day unit on the solar system with the teacher acting as a collaborator in the qualitative research design. Linguistic theory of everyday communication highlights how this teacher used the rapid flow of relatively unstructured information, typical of inquiry-oriented elementary classrooms, as an asset in guiding students to constructing knowledge relevant to their developing concepts. Her teaching skills are commonly associated with teaching language arts and reading but are shown to be important assets in teaching activity-based elementary science. The implications for elementary science instruction, inservice education for elementary teachers, and statewide systemic initiatives seeking to affect lasting changes across a broad range of elementary classrooms are discussed. (PR)

Paper presented at the annual meeting of the National Association for Research in Science Teaching, Atlanta, GA, April 15-18, 1993

# Navigating in a Sea of Ideas:
## Teacher and Students Negotiate a Course Toward Mutual Relevance

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Abstract

The distinction between the participant and spectator functions of language (Britton, 1970) are used to describe the teaching skills of a 4th grade teacher during a unit of instruction. Linguistic theory of everyday communication highlights how this teacher used the rapid flow of relatively unstructured information, typical of inquiry-oriented elementary classrooms, as an asset in guiding students to constructing knowledge relevant to their developing concepts. Her teaching skills are commonly associated with teaching language arts and reading but are shown to be important assets in teaching activity-based elementary science. I discuss implications for elementary science instruction, inservice education for elementary teachers, and statewide systemic initiatives seeking to affect lasting change across a broad range of elementary classrooms.

Navigating in a Sea of Ideas:
Teacher and Students Negotiate a Course Toward Mutual Relevance

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The distinction between the participant and spectator functions of language (Britton, 1970) are used to describe the teaching skills of a 4th grade teacher during a unit of instruction. Linguistic theory of everyday communication highlights how this teacher used the rapid flow of relatively unstructured information, typical of inquiry-oriented elementary classrooms, as an asset in guiding students to constructing knowledge relevant to their developing concepts. Her teaching skills are commonly associated with teaching language arts and reading but are shown to be important assets in teaching activity-based elementary science. I discuss implications for elementary science instruction, inservice education for elementary teachers, and statewide systemic initiatives seeking to affect lasting change across a broad range of elementary classrooms.

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## Introduction

While, well prepared, knowledgeable teachers do at times orchestrate highly organized sets of science activities, the typical lesson or unit of these same teachers is a more spontaneous affair (Nyberg, 1991; Tobin, Briscoe, & Holman, 1990; Tobin, Kahle, & Fraser, 1990, pp. 51-56). Much of our current knowledge of science teaching and learning in classrooms is built upon research structured around materials and procedures especially developed for the study (Driver, Guesne, & Tiberghien, 1985). Theoretical frameworks for those studies are designed to contrast children's concepts with conventional science principles.

Evaluating the more broadly conceived elementary science instruction of teachers whose primary expertise is in reading and language arts requires analyzing instruction through the lens of everyday language in the classroom. This contrasts with studies that use the structured language of scientific methods and the specific relationship of evidence to scientific principles. Most instruction and the accompanying student dialogue does not attain the coherence created by intervention studies that for example examine specific kinds of reasoning (Flick, 1991) or specific concepts (Nussbaum, 1979). In elementary classrooms where science is effectively taught, important learning is often forged from verbal negotiations as well as from evidence and experience.

Elementary teachers typically have strong backgrounds in language arts and reading. Good teachers develop successful pedagogical skills in these areas that help students improve skills in reading and writing as well as critical thinking and inquiry skills. These teaching skills would benefit science instruction if recognized as valuable.

But even good elementary teachers take few science and mathematics courses and the ones available to them are often poorly suited to their needs and interests (Tobias, 1990). The poor quality and quantity of teaching in elementary science is usually cast in terms of aversion to the subject matter and ignorance of its importance. This characterization of the problem focuses attention on deficiencies that mask important teaching skills that can actually help alleviate the problem. This narrow characterization can result in current reform efforts in science and mathematics education appearing as just another attempt to shore up the curriculum rather than affecting systemic change.

Informed and reflective elementary teachers are aware that lack of knowledge and appreciation for the subject matter precludes good teaching in math and science. But the problem goes beyond knowledge and appreciation to a lack of a conception as to how science and math education plays a role in and can be supported by the skills of a teacher primarily educated in language arts and reading. By creating such a conception, reform in science education can tap strengths in elementary teachers that will contribute significantly to improved science and mathematics instruction.

## Purpose

The purpose of this study was to document the science instruction of a 4th grade teacher whose teacher education program of 20 years ago led to a major in teaching reading with no specific coursework in science or science education. In recent years, she has taken steps to develop skills and knowledge in science and math education. The study focused on the planning and execution of a 31-day unit on the solar system with the teacher acting as a collaborator in the qualitative research design. The study had the following objectives:

- Describe good elementary science instruction planned and implemented by a teacher whose academic training was in reading and language arts.
- Analyze the relationship between oral discourse, writing activities, and learning in science by applying theory of everyday communication and the teaching of language arts.
- Identify implications for reform in elementary science education.

## Language and the Teaching of Science

Researchers have examined classrooms as micro-cultures that multiply productive thinking around the ideas targeted by instruction (Fleer, 1992: Tregaust, 1991). This work is supported by Vygotskian (1962) theory that verbal intercourse especially with adults is a powerful influence on the development of concepts in children. It also draws upon the perspective that knowledge is a social construction more than an individual construction. This view is at odds with contemporary constructivist theory whose dominant premise is that conceptual change is played out in the minds of individuals as if each were a little scientist (O'Laughlin, 1992). Over reliance on the epistemological assumptions of Piagetian constructivism has the effect of inappropriately applying the canons of scientific thought to learning in children. As O'Laughlin (1992) pointed out and as will be noted in the results of this study, "approaches such as these are of limited value in providing the foundation for a radically reformed science education. . ." (p. 799).

### Everyday Communication

The social dimension of knowledge construction is consistent with recent linguistic theory of everyday communication. Sperber and Wilson (1986) note that "hypothesis formation and confirmation, as it is understood in science, as a model of spontaneous comprehension seems at variance with observation" (p. 30). Two people never totally share the ideas that each is expressing to the other. Further, they do not derive the same assumptions from that part which they do share. The theory suggests mechanisms for how the ideas of students diverge from even well planned instruction (Osborne & Freyberg, 1985). In Sperber and Wilson's analysis of inferential communication, people derive the necessary speed of comprehension and response by paring away assumptions that may possibly explain the meaning of a communication unconsciously and uncritically leaving the remaining assumptions in a loosely structured whole. Such structures can be compared to Vygotskian (1962) "complexes" that represent various intermediate stages of concept formation. The strength of these loosely structured interpretations for ongoing communication does not rest in the conscious reconstruction of supporting assumptions, as in scientific reasoning, for these assumptions are not easily retrieved or examined in everyday thinking and communication (Norman, 1983). The strength lies in the relative strength of the mental models previously established (unconsciously) and in the relative strength of other existing assumptions which are contradictions.

Conversation is a mainstay of classroom discourse. Reflective, analytical thought does occur, should be encouraged, and continues to be the subject of important research. However, pedagogical content and practice in science can be informed by and effectively interact with the volume of ideas made manifest in a classroom environment that fosters high levels of verbal exchange. Highly verbal, interactive, and subject matter diverse settings are becoming trade marks of the emerging national standards for science and mathematics education (NCTM, 1989; Hoffman & Stage, 1993; Ahlgren, 1993).

Instructional Theory in Language Arts

Pedagogical content and practice in the language arts sheds light on our recurrent problem with science and mathematics teaching in K-12 classroom in general and the elementary grades in particular. Britton (1970) has had a major impact on instructional theory in language arts. His theory describes ways language is used when sharing ideas, as in classrooms. He distinguishes between speech that is used to get things done from speech used for the sheer pleasure of telling. The former is called "embedded speech" and relies on the current context for meaning. The latter is called "displaced speech" which has referents from some other context and some other time which the listener must be able to assume. Teachers or students will use speech that is embedded in the current context for example to inform, instruct, persuade, argue, and explain. Displaced speech is used for example in make-believe, chatting, story-telling, and gossip.

Embedded speech seeks to get the listener to "participate" with the speaker in the present context. This form of speech dominates most classroom discourse in math and science. In the participant role, teachers and students select their thoughts based on the external criteria of the situation, on observations that can be debated, or arguments that can be shown true or false. Displaced speech invites the listener to share like a "spectator" in the speaker's interest and enjoyment in what is expressed. In the spectator role, the speaker selects ideas from internal criteria that the speaker finds pleasing or personally interesting. The spectator function of language plays a small role in Piagetian constructivism. Piaget (1962) argued that language is arbitrary whereas the characteristics of the physical world are necessary. However, to a child a specific context requires the use of certain words, while the characteristics of the physical world, as expressed in scientific generalizations, may seem quite arbitrary (Karmiloff-Smith. 1979). Therefore, understanding and fostering spectator language becomes important when, as with the learning cycle model

(Lawson, 1989), teachers seek to promote constructive interactions between children's existing knowledge and the target concepts. The spectator role of speech is developed in language arts instruction and I will argue (with Britton's help) is important in the science classroom.

Through the language arts curriculum teachers regularly ask children to write or tell about past experiences in attempts to generate fluency of thought and to practice meaningful writing (Atwell, 1990). However, researchers in the areas of writing and speaking have wrestled with the long standing problem of stilted expression that relies so heavily on factors external to student thinking or experience that their own understanding is not improved. When students "do library research" the result is often plagiarism that results in a parody of the intended product. Students are so dominated by the words of others that they do not form their own thoughts. This creates a one-way street where students feel they must use language that shows they are "participating" in the ideas of other authors to the exclusion of their right as writers to invite others to be a "spectator" with them in their own thoughts (Giacobbe, 1986; Graves, 1978).

Role of Language in Learning Science

In science classes, students are typically asked to talk or write about situations that are disconnected from their lives and/or their culture. Even hands-on activities do not alleviate the need for students to make a reality check between what they are experiencing and what they are thinking. Activity-based classes can have marginal results where there are few opportunities to share ideas. Fleer (1992) identified the most successful science instruction of three elementary teachers as the one who "provided many opportunities for the expression and extension of children's thinking about the scientific phenomena they were investigating" (p. 393). This teacher promoted a shared understanding between herself and the children concerning their own ideas. She established the problem in a socially meaningful context and created activities that were appropriate to that context and that were respectful of the children's ideas.

Britton (1970) offers important insight concerning the role of language in classroom discourse that has significant implications for science teaching.

"As participants we generate expectations from past experience, put them to the test of actuality, and modify our representation of the world. ... But sometimes what happens is so unlike our expectations that we are not able to adjust quickly enough. Our representation cannot change as radically as what is apparently called for. But events do not wait. We participate as best we can and finish with a positive need to take the role of spectator in order to come to terms with it. If there is such an opportunity, the spectator may become comfortable enough to continue participation. If there is insufficient or no opportunity to engage in linguistic spectatorship, then we may merely *reject* the recalcitrant experience, go on basing our expectations upon a representation of the world in which such things 'simply don't happen'" (p. 118).

The rapid flow of ideas easily overcomes the ability of students to adjust to novel ideas or events in science classrooms. Contemporary models of science instruction emphasize the necessity for engaging student thinking about the target science concept near the beginning of instruction (Lawson, 1989; Osborne & Freyberg, 1985; Bybee, et al., 1989). But normal classroom discourse can inject new ideas at any point in these inquiry models. There is a dynamic relationship between student thinking during active inquiry and teacher-directed instruction (Hein, 1990; Flick, 1993). A detailed look at how these often distracting, usually divergent ideas can be handled to the benefit of learning science will inform science teaching.

## Collaborative Research Design

This is a descriptive study of one exemplary teacher and her students. I will use the pseudonym, Ms. Anderson for the teacher to maintain the confidentiality of her students. More specifically it is a study of Ms. Anderson's application of discussion and questioning skills, effectively eliciting verbal and written expression, use of community resources, and integration of hands-on activities to guide high quality learning in a science area of which she had only basic knowledge.

She taught a unit about space science from her repertoire built over a 20 year career carried out in the usually busy, often hectic environment of a full-time teacher. Science teaching is a regular part but not a dominant part of her yearly curriculum. This was not one of her "prized" productions like her Invention Fair or Designing a Home which incorporate major elements of language arts, math, and social studies as well as science. This unit represents the kind of weekly science instruction from a skilled elementary teacher who is overcoming a weak background in science. This report documents the processes by which the teacher and students converged on mutually relevant concepts that also represented significant learning in science.

### Students

The school is in an upper middle class neighborhood in a town of 50,000. There were 14 girls and 14 boys in the class whose average total score on the California Test of Basic Skills, 4th Edition, was in the 68th percentile. Eleven students had a total score above the 80th percentile and eight had a total score below the 50th percentile. There were two Afro-American students and one Hispanic student. Student backgrounds represent a cross section of American community and family life. Some students had broad experiences to draw from and others had few educational enrichments.

### Data Sources

My collaboration with Ms. Anderson involved 10 in-depth classroom observations of her, her students, and guest speakers. I met with her regularly over the course of the unit. Discussions concerning the objectives of this study began near the beginning of the school year and continued through the follow-up interviews with her students and into the following school year. In all, the collaboration represents more than 17 months of intermittent to intense interaction around her classroom (see Figure 1).

During our regular meetings about the solar system unit, we compared observations of the class and worked out differences in what we each thought was the conceptual focus. We discussed the content of future lessons and evaluated the content of previous lessons. Our discussions addressed the following questions: (a) How to achieve meaningful understanding of a complex topic: relationship of the earth, sun, and moon, (b) What is the role of language arts, particularly writing and speaking, in the science curriculum, and (c) How her background influenced the preparation and delivery of the unit.

The culminating experience of the unit was a classroom debate. Nine weeks after the completion of instruction I conducted structured interviews with 27 of the 28 students. One female student whose academic rank is at the top of the class declined to be interview in spite of the urgings of her parents and Ms. Anderson. These interviews focused on the central concepts of gravity, relationship of earth, sun, and moon, and the shape of the earth. They served to link the classroom discourse with well documented and important outcomes in science instruction.

All observational notes, interview transcripts, the transcript of the debate, the transcript of one educational film, and selections from each student's writing were entered into computer files for analysis by HyperQual (Padilla, 1989). HyperQual uses text searching and dynamic file organization capabilities of HyperCard® to aid investigation of verbal data. The analysis strategy for this study included use of key words and phrases to extract text relevant to the concepts of gravity, relationship of earth, sun, and moon, and the shape of the earth. In all the program aided in the analysis of over 45,000 words of text.

## Creating the Sea of Ideas

Ms. Anderson's 4th graders experienced an educational environment that stimulated them with activities, guest speakers, discussions, and a formal classroom debate. While the teacher describes herself as having basic knowledge about the science topics of this unit, she conducted stimulating and highly involving instruction. Figure 1 contains an outline of the observed instructional activities over a six week period.

The ideas were generated from roughly three sources: Ms. Anderson's instructional methods and materials, guest speakers, and students. Two guest speakers were from a local science laboratory where they received specific training on how to interact with students and teachers. I will use the guest scientists' contributions to the class along with one of Ms. Anderson's lessons to sketch the diversity of information available to students and the inherent complications and ambiguities of normal classroom presentations. The next section of the paper on Negotiation will discuss how good elementary teachers, like Ms. Anderson, use strategies and skills more common in reading and language arts instruction to foster relevant learning in science out of relatively unstructured information.

Guest Speakers

The first speaker had a prepared presentation that focused on ideas of relevance to Ms. Anderson's unit which included a "hands-on" activity as well as pictures and a practiced presentation. The activity was to construct a scale model of the solar system by placing students in appropriate places on the playground. The exercise was conducted so that virtually all the discussion of content relative to the scale, order, and distance of the planets was conducted outdoors while the students were being moved around into position. This logistical error made it extremely difficult for the students to make appropriate connections between the target concepts and the purpose of the activity. His presentation introduced a broad array of ideas through several questions. What are satellites? Why do we go into space? How will they get the pieces of the planned space station into orbit? How do they bring things down? Why would they put a telescope in space? The presentation examined various ways that NASA is planning to explore the solar system.

The second speaker, a scientist from the same research laboratory, described knowledge of earth derived from satellite and Apollo photographs. He referred to a globe of earth showing physical features in relief and other flat maps as "optical illusions" because they were "models" of the earth and the earth could be modeled in more than one way. He emphasized that "It was important to use the right map for the right reason." His reference to optical illusions appeared to perpetuate and even support erroneous thinking as will be discussed.

While these speakers presented essentially accurate science content with practiced methods, it remains to be seen how teacher and students should use this diverse information some of which may be difficult to understand or misleading.

Ms. Anderson's Instruction

Ms. Anderson conducted several hands-on activities and held science classes almost daily. She conducted discussions and writing activities related to speakers and to follow-up her own activities. One sequence of activities began by using creative dramatics where she dressed as the sun and talked about her "children," the planets. She used "parent" as a metaphor to describe how the sun "takes care" of the planets with heat and gravity. Rotation and revolving described how the planets "played". While students spontaneously fanned themselves and drew back when she got close, she introduced a large number of facts about the sun and planets.

Her introduction to the solar system "family" was followed by a hands-on activity that generated many useful ideas but also some unresolved complexities. She had students organized in groups to demonstrate gravity through the analogy of magnetism. All groups had a magnet and a paper clip tied to a string and taped to a desk. They quickly gained the skills needed to attract the clip without the magnet touching. The students pointed out how the paper clip was rotating, being spun apparently by the untwisting of the string when the clip was held in the air by the magnet.

She saw this as a meaningful part of the analogy and said, "Does this help you understand why a planet rotates as it revolves around the sun?" The exact meaning of this question was not clear within the context of the activity. Later Ms. Anderson said that it demonstrated to her how gravity holds planets in a way that lets them rotate as well as revolve. Classroom discussions and the follow-up interviews showed that most students did not clearly distinguish between the terms revolve and rotate. They did, however, make constructive use of the magnet analogy to gravity.

The effect on students of any particular statement is difficult to judge in the normally rapid flow of information. Even statements containing terms central to the main idea of the unit, which rotate and revolve certainly were, get entangled with other ideas or events, such as the magnet activity. Students need regular opportunities to confront these ambiguities and try to make sense of them. Ms. Anderson's view is that, "Conversation is important to children. That is how adults generate ideas, by talking things over. Kids need that opportunity too." By providing these types of opportunities, Ms. Anderson worked with her students as they negotiated a course toward ideas that were meaningful.

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Insert Figure 1 about here

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Negotiating: A Language-based Description of Inquiry Instruction

This report of Ms. Anderson's class is one that deliberately highlights the complexity of information in the day-to-day activity of an elementary classroom. Further it shows the large number of ideas that form what Sperber and Wilson (1986) call the "cognitive environment" of everyday inferential communication. Inquiry teaching methods purposefully increase the complexity of the cognitive environment and can make teachers, unfamiliar with the process of inquiry teaching, feel overwhelmed by the task of teaching science. They lose track of what they want to teach and fear that the instructional process does not converge on answers to scientific questions (Flick, 1989).

Ms. Anderson achieved convergence through her use of student writing and classroom discourse. Convergence was not on particular correct answers, but on what the unit was generally about. This was achieved through a process that engaged students in the spectator function of language (Britton, 1970). Contrasting student dialogue in one of Ms. Anderson's lessons with one of the guest speaker presentations shows the difference between the participant and spectator functions of language. The comparison also shows the difference between children choosing language to suit the external criteria of the speaker as contrasted with more internal criteria used during Ms. Anderson's lesson.

<u>Participant Language</u>

The first speaker had been discussing maps and their relationship to a spherical earth. The class examined the full-earth picture centered on the Persian Gulf taken during the Apollo 16 mission. He asked, "What time of year was this full-earth picture taken?" His point was that it would be winter in the northern hemisphere because the photo shows full sun angled toward the southern hemisphere. Students attempted to "participate" as best they could with what they knew about earth and sun. Their responses included:

"Clouds are forming, therefore if must be December." (The local weather is cloudy in winter and very sunny in summer.)
"There is no way to tell because the earth is always turning."
"Weren't the astronauts in isolation? (Ms. Anderson had talked about lunar astronauts being held in isolation after their return.)
"Isn't there a twin?" (Reference to the possibility of a twin earth, Nemesis, mentioned by the other guest speaker.)
"Always the same picture because it is winter. You couldn't take a picture in summer because you'd be tuned around facing the sun and you'd burn up."

Students wero groping to fit what they knew to this subtle problem. Britton (1970) points out that there are subtle differences between students telling us of their experience and students inviting us to share experiences with them. The comments were divergent and conceptually scattered. While the speaker allowed students to express several ideas, he did nothing with this wide ranging flow of information. His treatment of the context of the question did not allow students to explore other ideas the found relevant. He stated the correct answer at the end with no further discussion. Students were "left with the positive need to take the role of spectator to come to terms with" this problem (Britton, 1970).

<u>Spectator Language</u>

By contrast, Ms. Anderson conducted a follow-up discussion of her own introduction to the solar system as the "mother" sun with planets as "children". The students had taken notes and were now asked to refer to those notes and discuss what then had learned.

"The sun has a magnetic field."
"Mercury goes around more often than the other planets."
"Sun is made out of dirt and gas." (A mixed reference to comets which Ms. Anderson points out.)
"If one planet gets out of place then they may explode."
"If Pluto blew up it would take 5 hours before we would see it."
"If the sun exploded we'd be in big trouble, the pieces would really demolish the earth."

This recitation in participant language turns toward spectator language and Ms. Anderson capitalizes on the opportunity. It is significant to note that the ensuing discussion about exploding planets is totally unexpected and from the standpoint of a "structure of the solar system" discussion an unnecessary diversion. However, Ms. Anderson does not see it that way. She describes the following episode as "A ripple effect, where one student introduces an interesting idea and you can see it ripple out across the class like throwing a stone into a pond." She allowed students to expand their thinking beyond the ideas brought to class and created opportunities for new ideas from speakers, from activities, from each other, to influence their learning about the solar system. Ms. Anderson asked the class to "take 60 seconds of thinking about what would happen if the sun exploded." This had the effect involving the whole class and provided time for students to disengage from the immediate constraints of the lesson review and begin sorting and selecting information based on other criteria in the rapid thinking of everyday conversation.

"If we were 45 miles away from the sun we'd burn up." (Ms. Anderson suggests looking up the distance from sun.)
"The sun would go up into the air and come into our atmosphere and start fires."
"After it blows up everything would be dark."
"After about 1 second our atmosphere would be dark and we'd be dead."
"As soon as it hits the earth all the planets would be gone."
"Planets are made out of gases and sun would start them off."
"Since there is no gravity in space the little pieces would just float around."
"If it does blow up it would freeze us to death."
"All the planets would just be floating around."
"I think the solar system never stops."
"How could it stop?"
"What would be out there?"
"Heaven!"

This is one example of several episodes in Ms. Anderson's instruction where she created opportunities for students to expand cognitive environment of ideas. The sea of ideas, if you will, flooded the minds of students and the heretofore relatively unstructured complex of information was made relevant by the students. The term 'relevance' has a particular meaning here. It is commonly used to mean of practical significance in student lives. Relevance is usually invoked in relation to hands-on investigations where the concrete materials are assumed to make ideas meaningful because the objects are in student hands. Ms. Anderson is generating a different kind of relevance. It is an intangible form of relevance born of student intellect and manifest through language.

Principle of Relevance

Sperber and Wilson (1986) define this intangible form of relevance in terms of spontaneous, inferential comprehension. In everyday conversation people use perceptions and ideas as premises for inferring new information in the blink of an eye. There are a large number of ideas stated or implied during normal classroom conversation. All these ideas are not mutually known by both teacher and students. The best that can be said at any one time is that some of these premises are a part of the students' cognitive environment and some are a part of the teacher's cognitive environment. I have treated the students as though they have a collective mind for the sake of simplicity. Yet, teachers are regularly forced by the constraints of time to make just such an assumption in order to make judgements about what the class should do next.

An idea that is part of a cognitive environment does not mean that that idea will be used in comprehension only that it can be used. The "principle of relevance" states that the listener (teacher or student) makes the assumption that a communicative act will be informative (Sperber and Wilson, 1986). This means students will assume that the various stimuli (e.g. statements, body language, or materials), are information-producing. Sperber and Wilson suggest that it is difficult to assume that both speaker and listener have the same knowledge. However, the principle of relevance implies that mutual understanding can be achieved by processing the same stimuli in similar cognitive environments which have been shaped by repeated attempts to communicate.

Ms. Anderson's discussions were in effect designed to produce similar cognitive environments by providing opportunities for students to share the way they processed ideas. The guest speaker's discussions were designed to convey information whose relevance was based only on his understanding. He did not see the student's questions or comments as conveying information.

Some ideas are more relevant than others and it may take more mental effort to produce relevance from one idea than another. Everyday communication implies that human information processing assesses these factors rapidly and largely unconsciously. Greater relevance is achieved when the cognitive environment generates large numbers of new ideas and when this is achieved with relatively small mental effort. Ms. Anderson's class discussions were often free flowing and generated a large number of ideas from many students as a result of the "ripple effect."

Going Beyond the Data through Writing

Ms. Anderson followed up each activity or guest speaker with a writing activity. In the case of the scientist's presentation described above, students wrote a thank you letter. She and the scientist agreed that students would respond to a particular question that would give him useful feedback on the effectiveness of his presentation. The question was, Is there really a dark side of the moon?

The question was not clear the following day when students wrote the letter. The intent was to probe their understanding of how the moon is illuminated by the sun and how that looks from earth. The responses indicate ways students produced relevance from their cognitive environment. In this environment of ideas some were given more strength than others and clearly, some of the ideas were contradictory or ambiguous. For instance, two students processed the question in the context that space is generally dark unless you are facing the sun. They each reached a different conclusion.

"Yes, because it is not facing the sun."

"No, because there is no light on the other side of the moon. There is one light which is the stars but that wouldn't be enough light. If there was another sun there would be enough light but there isn't. There may be one but it is not close enough."

There were responses that found relevance in the way the earth and moon are positioned in space.

"Yes, because the sun is shining - reflecting - off only one side of the moon."
"I think the moon looks bright on another side of the earth."
"No. ... The reason that I think that is because sometimes I go out at night and every night the moon is in a different place. I think it is because of the way it turns."
"No, the dark side of the moon isn't really dark. If you were an astronaut standing on the moon, no matter where you were on the moon, the moon would still be bright."

Ms. Anderson's letter was an invitation to look beyond the data which is almost always confusing or contradictory when partially formed concepts fail to create coherence. As a student this frees me from the constraints of how others have said things. I may become a spectator of my own thoughts and to generate new thoughts. This allows me to overcome the inherent confusion in the question "Is the dark side of the moon really dark?"

Vygotskian (1962) complexes, abound when students are learning something new. They must be worked out, not by being told, but by producing relevance, that is new assumptions or ideas, in the company of others who are leveraging their thinking by generating relevance also. In this way, students will not "reject the recalcitrant experience", but become comfortable enough with the ideas to continue in the participant mode to work out the details (Britton, 1970).

A Classroom Debate: Is the Earth Round?

Ms. Anderson ended the unit by conducting a debate about whether the earth is round or flat. She had already introduced the problem of dropping a ball into a hole dug all the way through the earth. Her source was a book (Gardner, 1971) she found while browsing through the school library. I remarked that research had shown that children harbor interesting ideas about the shape of the earth (Nussbaum, 1985). She described two books they had read as part of language arts prior to the science unit. They dealt with time travel (Greer & Ruddick, 1983) and fantasies about medieval times (Winthrop, 1985) which she noted was back when they thought the earth was flat. She used these books to set a context for thinking about the shape of the earth and some activities from Great Explorations in Math and Science (GEMS) "Earth. Moon, and Stars."

Planning involved brainstorming, drawing pictures, and library research. Both sides of the debate were encouraged to identify the arguments of the other side and be prepared to counter them. Students were told that they would have to think like they did in medieval times and that they could not use any information gathered from space explorations such as photographs of earth. It became impossible to keep discussion of some of this data out of the debate. The content of the debate is another example of the generative power of Ms. Anderson's methods and her navigational skills that lead students to examine the main ideas through language-based activities.

While the language of the hour-long debate was often in the participant mode, the days of preparation were concerned with stories about travel, the appearance of the earth, gossip about the other group, the weakness of their ideas, and general chatting all of which Britton (1970) identifies as indicative of spectator language. The dialogue between the debate teams, supported by notes and coaching from other members of the class, also represented the generation of relevance by a group process where the students have significant control over the cognitive environment.

The following example was stimulated by Ms. Anderson prodding the groups to explain day and night. The dialogue is an example of on-the-spot responses representing reasoning at conversational speed to create relevant statements. Consecutive numbering of statements are in parentheses and the signed numbers are debaters for (+) and against (-) the proposition "The earth is round."

(14) +4 If flat, it would always be day and if it turned over we'd all fall off into space.
(15) -5 We rotate and the moon would be on one side and the sun on the other side.
(16) +2 If the earth were flat, but it isn't it is round, and the earth is not the center of universe the sun is and the earth rotates and revolves around sun (hand gestures).
(17) -4 Everything rotates around us. (Reference to Medieval thinking.)
(18) +4 That's not true, we rotate around sun and moon around us.
(19) -4 How do you know?
(20) +4 (silence)
(21) -2 We rotate like a Frisbee
(22) +5 Then the sun would always shine on us and it would be day (all night) all the time
(23) -2 The sun is down low on one side and the moon down low on the other end and so the sun can only shine on one part and the moon can only shine on the other
(24) +2 If the earth was flat and rotated like a Frisbee, then one side would be just dim and the other bright. Sun does not rotate around the earth, the earth, if it was flat, would rotate around sun like this (uses hands) and it could be day all on one side and night all on one side.

Other sequences generated ideas on the nature of gravity, a flat versus a spherical earth, the problem of observing and tracking stars to determine the motions of earth, the paths of birds and clouds in flight across a flat versus round sky, and the relationship between the apparent flatness of our planet with the apparent roundness of other planets and our moon.

## Interviews

Ms. Anderson and I decided I would conduct interviews to validate the outcome of her instruction against other investigations of earth, moon and sun concepts. The exact nature of the interviews was motivated by her own classroom discussions concerning the nature of gravity with holes dug through the earth (Gardner, 1971) and after reviewing written responses to "Is the dark side of the moon really dark?" The protocol contained elements from Nussbaum and Novak (1976).

Nussbaum and Novak's (1976) study followed by additional work by Nussbaum (1979) has established a benchmark for research on children's thinking about earth as a cosmic body. Their work examined five categories of thought that describe a progression toward an understanding of earth in space that is consistent with most observations. The categories, or Notions of earth as a cosmic body, show how children interrelate three developing concepts in order to interpret common observations of the heavens. These concepts are the shape of the earth, the shape and extent of space, and gravity. Briefly, the five Notions are:

Notion 1. Earth is flat, with space limited by an absolute ground (down) and sky (up).

Notion 2. Earth is two hemispheres with the lower portion being the ground and the upper portion being the sky or air and space exists outside of these hemispheres.

Notion 3. Earth is spherical in limitless space but down is absolute and oriented with an upright body. A ball dropped at the equator falls into space and "maybe hits a planet or moon."

Notion 4. Earth is in unbounded space but up and down are oriented toward the earth's surface and not the center. Balls tend to fall into holes slanted toward the surface and not toward the center of the earth.

Notion 5. Earth is a sphere, in limitless space, with gravity acting toward the center.

The students were interviewed one at a time in a work room away from classroom distractions nine weeks after completion of the unit. The portion of the 30-40 minute interview reported here used an adaptation of Nussbaum and Novak's (1976) procedure. The interview protocol is discussed in detail in Nussbaum (1985). Students were shown diagrams for the "Water in bottles", "Dropping balls" and "Holes in the earth" problems. As part of our initial planning for the interviews, she asked the students to respond to a set of the Nussbaum (1985) drawings as a paper and pencil survey to provide feedback on student thinking midway through the unit. The protocol was embellished by the use of props: various size balls, Styrofoam balls with appropriate holes in them, and a pencil for probing the holes. The following is standard wording I used for each of the problems.

1. Water-in-bottles Problem.
The circle represents the earth with a pair of bottles placed on the north pole and another pair place at the south pole. One bottle in each pair is shaded to show it is half filled with a liquid. Draw a stopper in that bottle so that the liquid can't get out. Shade in a portion of the open bottle to show that it also has some liquid in it but it remains open. Do the bottles at the north pole appear any different from the bottles at the south pole? You may use any of these props to help you explain your answers.

2. Dropping-balls Problem.
Three people are standing at different places on the earth (two on the equator and one at the south pole). Each one has a ball. Draw a line indicating where the ball will go after each person drops their ball.

3. Holes-in-the-earth Problem.
3A. A hole has been dug completely through the center of the earth going north and south. Use this pencil to push through this (Styrofoam) ball. What would happen if a person placed a ball in the opening of this hole that goes all the way through the earth?

3B. A hole has been dug completely through the center of the earth going east and west through the equator. Use this pencil to push through this (Styrofoam) ball. What would happen if a person placed a ball in the opening of this hole that goes all the way through the earth?

3C. Stick your pencil into this ball and notice that one hole goes part of the way toward the center. The other hole goes at an angle from the first (not toward the center). What would happen if a person placed a ball at the opening of these two holes? Which hole would the ball drop into?

To be classified as holding a particular Notion, students had to answer each of the questions in a consistent manner. Where Notion 3 statements, for example, were mixed with Notion 4 statements, the student was classified as Notion 3. Half of Ms. Anderson's class thought of the earth as a sphere, in unbounded space, with gravity acting toward earth's center (Notion 5). Just under 30% held Notion 4 and about 20% held Notion 3. There was no consistent indication of Notion 2 and none of Notion 1. This compares with Nussbaum's (1979) study where Notions 3, 4, and 5 were held by roughly 60% of the sample of fifty 6th graders instructed in this subject. The comparison emphasizes that not all students in this age range will come to hold Notion 5. Additional experience and reflection is necessary to continue sorting out the complex relationships of earth, sun, and moon. Five students in Ms. Anderson's class showed clear movement toward Notions 4 or 5 when comparing the pencil and paper survey with interview results.

These results validate the outcomes of Ms. Anderson's instruction as promoting important learning in science with students of wide ranging achievement scores whose mean score was slightly above the national average. Brief exposure to portions of the GEMS materials which drew heavily from the Nussbaum research probably affected the number who held more complete concepts about earth.

## Implications for Reform

Ms. Anderson helped her students improve in their understanding of a complex concept as much from her skills in teaching through language as she did through her developing knowledge of science and science teaching. Her sense of the importance of exploring seemingly incidental ideas like an exploding sun, holes dug through the earth, and a twisting paper clip in a magnetic field gave students opportunities to observe thinking in the detached mode of spectator. The classroom debate and subsequent interviews suggest that students felt confident in continuing the process of working out the details of these concepts as a participants. These opportunities were developed by getting students to write about their experiences then sharing those experiences later, by relating the context of a current problem in a science lesson to the imaginative world in a novel, and by initiating and supporting divergent, expressive discussions.

This in-depth look at one classroom should be studied and replicated by science education reformers for the following reasons. The upper elementary and middle school grades are when students become aware of science as a separate area of study and begin to learn of its possibilities as a life's work. Good teachers in these grades have skills and knowledge that get students to think critically, skeptically, and cooperatively through effective uses of language. These skills are important for maintaining science in the curriculum in a way that students see it as an interesting and viable alternative for further study. Ms. Anderson not only is improving her knowledge in science, she is applying her skills as a teacher of language to enhance the processes of inquiry in science teaching. When elementary teachers are tapped again for in-service programs to reform science teaching, the methods of good language arts and reading instruction should be woven into that portion of the program devoted to pedagogy. The result will be a new conception of how science education plays a role in and is supported by the skills of an elementary teacher primarily educated in language arts and reading. Elementary science will continue to be lead by teacher with this academic bias if instruction remains integrated in self-contained classrooms.

National goals of science education reform efforts call for knowledge, scientific habits of mind, and critical thinking to become woven into the fabric of education (NSF, 1990). Ms. Anderson's ear for student thinking and idiosyncratic interests suggests that special attention to and training for engaging children in oral and written discourse has a critical role to play in activity-based science learning. Classroom discourse in science has been used to highlight misconceptions, elaborate active science lessons, and examine the wording of science principles. Each of these is important but they focus on the participant function of language. Scientific habits of mind include being skeptical yet being open to other ways of thinking. These forces on children's thinking must be relieved by opportunities to detach and speculate as a spectator lest we cause a tear in the fabric of their education.

This attention to language suggests a new dimension of the learning cycle. I would call this phase Expansion. This is different from the early use of the term meaning expansion of the target concept (Lawson, et al., p. 4). Ms. Anderson demonstrated how to take the normal, uneven flow of classroom events and capture opportunities to allow students to expand their thinking beyond what they bring to class, beyond statements of science principles, beyond what is predicted to the unexpected.

Weaving long-lasting, systemic change in elementary science and mathematics education means crossing many threads. There will be threads for knowledge, critical thinking, and habits of mind but they will be crossed with the weft of teacher skills pulling threads of opportunities to expand student thinking in unpredictable ways. At times this thinking may sound like story-telling, chatting, or recounting interesting experiences. Programs of systemic reform intended to create new modes of teacher education and staff development would benefit from detailed study of children's dialogue and writing that seeks to make children spectators of their own ideas as well as participants in the ideas of others.

FALL 1991 Planning

| | |
|---|---|
| Sept. 30 | Meet to discuss role of writing in science instruction. |
| Oct. 18 | Discuss language arts in science. |
| Nov. 7 | Instructional approaches in science. |
| Feb. 7 | Plan classroom observation of unit on space. |

WINTER 1992 Project

| | |
|---|---|
| Feb. 11 | Initial visit to classroom. |
| *Feb. 13 | Speaker #1 Solar System model and Space Program. |
| *Feb. 18 | Speaker #2 Mapping from space. |
| *Feb. 19 | Sun & Planets family analogy. |
| *Feb. 20 | Magnet activity. |
| *Feb. 25 | Discussion: Follow up of magnet activity (exploding sun). |
| Feb. 26 | Create a planet activity. Begin reading Castle in the Attic. |
| Feb. 27 | Students begin research for reports and posters. |
| March 3 | Martin Gardner's holes dug in the earth problem. |
| March 5 | Students view moon through telescope in the morning. |
| March 10 | Paper/pencil survey of Nussbaum problems. |
| *March 11 | Examine student reports and posters. |
| *March 12 | Measuring distance with similar triangles |
| March 16 | Film: "Why we don't fall up". |
| March 17 | How we know the earth is round: GEMS Earth, Moon, & Stars. |
| *March 18 | What do Medieval people believe about earth. |
| *March 19 | Small groups debate preparation: brainstorm ideas & drawings. |
| Mar. 20-27 | Grading week: Parent conferences |
| *March 24 | Debate video taped |

SPRING 1992 Follow-up

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|---|---|
| June 1-5 | Interviews |

SUMMER 1992 Debrief

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|---|---|
| June 10 | Discuss interviews |
| June 17 | Observe class and discuss project. |
| June 22-23 | Discussion of project |

WINTER 1993 Reflection the following year

| | |
|---|---|
| Feb. 1 | Observe class, discuss last year's project. |
| Feb. 17 | Discussion last year's project. |
| Feb. 26 | Observe class, discuss last year's project. |
| March 29 | Discuss draft of report. |

Figure 1. Outline of collaborative activity with Ms. Anderson and major events in her classroom during the instructional unit on space. In-depth classroom observations are marked (*).

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