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## Chapter 6

Triggering Science-Forming  
Capacity through Linguistic  
Inquiry

Maya Honda and  
Wayne O'Neil

In this paper we discuss curriculum development in science education that we have been doing for the past several years in two somewhat different educational settings. The goal of our work is to activate the science-forming capacity available to us all by virtue of our very nature (see section 3), or as Sylvain Bromberger (1992: 1–2) has so elegantly written:

We start out with little prior information about [the] world, but we are endowed with the ability to come to know that there are things about it that we don't know, that is, with the ability to formulate and to entertain questions whose answers we know we do not know. It is an enormously complex ability derived from many auxiliary abilities. And it induces the wish to know the answer to some of these questions. Scientific research represents our most reasonable and responsible way of trying to satisfy that wish.

For reasons given in some detail below, we believe that the questions that arise in linguistic inquiry represent a reasonable way to induce in students the wish to know the answers to some of their questions, and thus to introduce them to scientific research.

### **1 Background**

Over a four-year period (1984–1988), we wrote, piloted, and tested a set of linguistics lessons, part of a four-week unit on the nature of scientific inquiry meant to replace the standard unit introducing junior high school students to general notions of scientific method. The unit—in various forms, but always with a linguistics component—was developed during this period by a team of secondary school science teachers and university people. The linguistics component was widely tried out and continually revised in after-school sessions with small groups of students and finally put to the test in regular science classes at the seventh- through twelfth-grade levels in Cambridge, Newton, and Watertown, Massachusetts, with

the emphasis being on its use in the seventh grade, where formal science education normally begins in the school curriculum in the United States. We (together with Carol Chomsky and Risa Evans of the Harvard Graduate School of Education, in the earlier and later stages of the work, respectively) were responsible for the linguistics part of the unit; for choosing and piloting linguistics problems in after-school sessions; for formulating and writing lesson plans and trying them out in real time; for working with teachers in their classrooms as they used the lessons; and for assessing the effects of the lessons (see Carey et al. 1986, 1989, Chomsky et al. 1985).

This linguistic work was done in a corner of the Harvard Graduate School of Education's Educational Technology Center, the U.S. Office of Educational Research and Improvement-supported center in which questions about the appropriate school uses of technology were to be answered and in which questions about improving math and science education were partially addressed. "In a corner" of the Educational Technology Center, because our work was not—strictly speaking—what the Center was about; for we ran, and continue to run, a decidedly low-tech enterprise, one requiring only paper, pencil, chalk, blackboard, and minds (both the teachers' and the students').

This project was different from other such linguistics programs that we have been involved in, or that we know about, because we were working with secondary school science teachers and in the science curriculum, and not with teachers of English or language arts, the place in the school curriculum that linguistics had tried to move into beginning in the 1950s—with only limited success. See, for example, the linguistics component of the Oregon Curriculum Study Project materials that O'Neil initiated, developed, and contributed to in the mid-1960s (Kitzhaber 1968).

In addition to Kitzhaber 1968, English-based curricular materials in which linguistic inquiry for the primary and secondary school curriculum has been proposed and/or developed have appeared at several times during the past three decades (see, for example, O'Neil 1969, Keyser 1970, and Fabb 1985).

Analogous, non-English-based school materials have been tried out among desert aboriginal communities in central Australia and among American Indian communities in the southwestern and midwestern United States (see, for example, Hale 1975, White Eagle 1983). This work exploited the low-cost benefits of linguistics-based science curriculums in third-world and marginalized communities, where the expense of equipping and maintaining laboratories is a significant constraint on

science education—a matter not to be overlooked at less well endowed, first-world schools and colleges during this time of extreme academic recession.

In these two radically different settings, results of the preliminary studies were highly encouraging. As discussed below and in Chomsky et al. 1985, the classroom trials were quite successful. Classroom observations showed that students generally grasped the problems, had no trouble generating the relevant data, and were able to make the necessary linguistic judgments easily. They formulated relevant questions, came up with tentative answers, and looked for counterexamples, revising their hypotheses as needed. With help and through discussion, they worked out principles that amounted to serious explanations of the data.

The aboriginal and native American Indian experiments were likewise very encouraging, although measures are not yet available to document success in these projects.

Although we have not used these linguistics materials in the schools since 1988, our interest in the issues that they raise and the problems that they are aimed at continues, but our work has been redirected in the following way: If one understands that the way teachers are educated is central to advancing science education, why not try to affect teacher preparation? In a small way we are now doing that at Wheelock College in Boston, a major regional center for preparing early childhood and elementary school teachers. There, in a class we teach on bilingualism and language acquisition, we use lesson plans similar to those described here in the linguistic education of our students. Although the central goal of this instruction is to teach the students something about the knowledge that is acquired in both first and second language acquisition through an examination of their tacit knowledge of their own languages, another goal is to overcome their ignorance and fear of the scientific style. In the next year or so we hope to be able to present a linguistics course at Wheelock College that will satisfy in part the undergraduate science distribution requirement at that institution.<sup>1</sup>

Thus, beginning in 1990, our new work became directed toward the undergraduate college curriculum, in particular toward students who are being educated to work as teachers in primary schools. In this setting we plan to incorporate a certain amount of basic mathematical logic into the work as well. In what follows we discuss our work, drawing primarily from our experience in the schools (the most controlled setting in which we have worked), as well as from our more recent experience at Wheelock College.

## 2 The Problem(s)

Our work is meant to address a general and well-documented problem in the scientific education of the greater part of the school-age population of the United States: after years of sitting in science and mathematics classrooms or avoiding these experiences as much as possible, students have little or no conceptual grasp or appreciation of the science and mathematics enterprises. Moreover, as presently constructed, the introductory science and mathematics courses available to first- and second-year college undergraduates generally do little to change their narrow, school-bred notion that science is simply a fixed body of knowledge given by authority and that mathematics is a set of algorithms for cranking out the right answers.

This problem is further compounded at colleges like Wheelock whose student populations are often overwhelmingly female and consequently both underprepared in science and mathematics and fearful of these subjects, and thus lacking in intellectual confidence. Women's loss of interest in mathematics and science and their loss of confidence in their ability to do mathematics or science are largely shaped by negative early school experience (American Association of University Women (AAUW) 1991, 1992). The undergraduate education of prospective teachers of young children—the majority of whom are women—must find ways to foster positive attitudes toward science and mathematics and must develop students' ability to work in these areas, for they will inevitably in turn influence their own students' early school impressions of and attitudes toward these subjects, especially as role models for their female students (see AAUW 1991: 10–12).

The "crisis" in science and mathematics education, especially in the education of women, is well documented in studies and reports from numerous sources, including the AAUW, the National Science Foundation, the National Council of Teachers of Mathematics, the Mathematical Sciences Education Board (MSEB), the National Research Council, the American Association for the Advancement of Science, and the Massachusetts Institute of Technology (Latanision et al. 1991, 1992).

Comment on the crisis is ubiquitous; In a recent issue of *Science*, for example, the guest editorial is entitled "Science Education: Who Needs It"—the answer being that we all benefit/suffer from good/bad science education (Hackerman 1992:157). This view can easily be extended to mathematics education, for we all benefit/suffer from good/bad mathematics education as well.

However, little is done in schools or in teaching (as opposed to research) colleges and universities to actively engage students in scientific inquiry, to bring together in a serious way their study of the various sciences and branches of mathematics, or to build students' confidence in their ability to do science and mathematics.

Moving beyond these general and specific descriptions of the crisis, a number of proposals have been made for change in both mathematics and science teaching that emphasize intellectual challenge (e.g., MSEB 1990, National Science Teachers Association (NSTA) 1992).

Given its present direction and form, our work now aims to achieve the following educational goals:

- To develop in students, and in particular in future teachers of young children, an understanding of the scientific achievements in linguistics (as well as their limits) and of linguistically relevant branches of mathematics (logic and set theory).
- More importantly, to establish an intellectual climate in the classroom in which students can develop in themselves a scientific style of argumentation, or a deep appreciation of it at least, in linguistics, in related branches of mathematics, and in the connections among these fields.
- By meeting the first two goals, to help students build confidence in their ability to deal with unfamiliar problems in science, separating these from questions or mysteries that are not—at least for the moment—subject to rational inquiry.

## 3 Rationale

The novelty of our work is that it takes linguistics—the best understood of the cognitive sciences—as its domain of scientific inquiry, linking it in its currently developing form with the independently motivated study of mathematical logic so as to reveal the relationships between subjects in a way that is rare, but desirable, in the science curriculum. For connecting subjects up in a serious way will better lead students to a deep understanding and appreciation of scientific ideas and argumentation (see Eisner 1992, citing NSTA 1992).

This novelty derives from our belief—also novel—that a science education can only fruitfully and fairly build on the mind's science-forming capacity, taking that expression to refer to the idea that in making science, humans are natively endowed to do science as well as tightly constrained in their options and perhaps even in what they can make science about.<sup>2</sup>

We believe that these constraints are also at work in the core areas of what we refer to as “natural” mathematics: “the simplest mathematical ideas [that] are implied in the customary lines of thought of everyday life and [that] all sciences make use of” (Newman 1956:1747).

This view of the mind guides our curriculum development toward phenomena that are conceptually accessible to students, that is, those that not only challenge their already existing ideas, but for which possible explanations are also within their grasp. This view of the mind has also guided our pedagogy toward the Socratic, and toward cooperative teaching and learning.

As a matter of definition, all students speak at least one language natively and thus have tacit knowledge of a language. Their tacit knowledge of other languages ranges from native or near-native fluency in a second language to knowledge at various levels of second, third,  $n$ -th languages. Our linguistic work builds on this largely tacit knowledge in the belief that depth of scientific understanding of knowledge of language can begin to be reached through Socratic introspection and cooperative inquiry.

By virtue of their mathematics education and miseducation, however, students end up with more than a tacit knowledge of number, another faculty of human cognitive capacity (see Gelman 1978)—one that, on Chomsky’s view, lay largely unused for most of the course of human evolution. Human beings have number because of what we are and where we are. It was “[Bertrand] Russell [who] once wrote that we would not have developed the concept of number had we lived on the sun. Perhaps [then] the opportunity to employ those faculties of mind that present us with a world of individual objects provides a triggering effect for the growth of the ‘number faculty,’ but beyond that it seems reasonable to suppose that this faculty is an intrinsic component of the human mind” (Chomsky 1980:38–39).

Thus, it is our view that like the linguistics curriculum, the related mathematics part of our curriculum will build on the tacit knowledge that students bring to these studies simply by virtue of their cognitive maturity. On this view, Aristotelian logic is then understood to be a representation of the way human beings ideally think; sets and numbers are the central concepts of intuitive mathematics; and “scientific method is simply,” in the words of Randolph Bourne, “a sublimely well-ordered copy of our own best and most fruitful habits of thought” (cited in Fox 1985). In the same way, Euclidean geometry—a subject that would naturally parallel the course of study proposed here—makes sense of the three-dimensional

space that our visual system presents us with, rather than the  $n$ -dimensional space (invisible to the mind’s eye) that physicists argue for.

“Why linguistics in the science curriculum?” is, then, a question raised over and over again by the school and college people (teachers and students) that we work with.<sup>3</sup>

Since it is insufficient to answer this question simply by indicating the novel aspects of our work, we provide the following detailed and lengthy response.

First of all, linguistic inquiry meets the basic pedagogical principle of the proposed lessons: that the material be in some sense conceptually and readily accessible, and that the students (as well as the instructors) have a rich prior experience that will guide their inquiry more or less straight in an interesting fashion. From this perspective, linguistic inquiry appears to be a fairer way to appeal to the science-forming capacity than what usually goes on in the science classroom.<sup>4</sup>

In general, students are introduced to science in areas where their experience is impoverished and/or where their commonsense understanding is strikingly at odds with things in nature. Thus, very little inquiry is possible in class or laboratory encounters in which many of the problems of science seem—from a commonsense point of view—quite unproblematic to the students. Much of cosmology, for example, deals in questions that simply do not arise in the world of common sense: whether the sun rises and sets, or whether our sense that it does is artifactual; whether the earth is spherical or not; whether it is revolving and orbiting through space at tremendous speeds or not; whether the universe is expanding or contracting; whether the visible objects of the universe account for merely 1 percent of its mass or not; whether black holes exist or not, and if they do, whether they are best understood as two-dimensional or as four-dimensional objects; and so on. Or consider something more commonplace: “the so-called *Taylor instability*, whereby if you turn over a glass of water, the water will spill although the air pressure should be sufficient to hold it in the glass—as, in fact, it does if, to prevent the instability, you place a sheet of paper over the glass” (Rossi 1990:81). In our commonsense physics water does what it is supposed to do, and the fact that the water does *not* spill when the glass is covered with a sheet of paper is completely counterintuitive, having nothing to do with the porosity of water or atmospheric pressure, which are themselves not notions readily available to common sense.<sup>5</sup>

An examination of one’s language, on the other hand, can immediately provide a set of problems and an area of inquiry that has certain advan-

tages for students. For example, why is it not possible to contract *want to* to *wanna* in fast speech whenever—so to speak—you “wanna”? Simply consider the grammaticality contrast between the contracted forms in sentences (1a) and (1b), and the ambiguity of (1c) with respect to contraction, where “\*” indicates grammatical deviance of some sort.

- (1) a. Where do you *wanna* go? ← Where do you want to go?  
 b. \*Who do you *wanna* go? ← Who do you want to go?  
 c. Who do you *wanna* visit? ←?- Who do you want to visit?

Apparent mysteries of this sort—in which the null hypothesis fails—are readily turned into questions, which can then yield answers of general interest and considerable depth. For further development of this and other examples, see section 4 and appendixes 1 and 2.

We have learned from our curriculum work at both the secondary and college levels that in linguistic inquiry, where there are few solid answers to offer them, students can come up with quite interesting hypotheses and come up with them rather quickly (see Chomsky et al. 1985).

Moreover, since scientific investigation is generally attempted in areas of experience where explanation is in conflict with students' commonsense notions or intuitive science (see, e.g., McCloskey 1983, Carey 1986), linguistics has a distinct advantage—for as far as we are able to understand it, there is no commonsense linguistics of any depth for linguistic theory to be in tension with, nothing like the commonsense mechanics, say, that undercuts a student's coming to terms with Newtonian mechanics.

On the other hand, although there does not appear to be a commonsense linguistics more complicated than the notion that a language is a list of words, any attempt to look at language in a scientific way is in tension with school grammar and other such sorts of language mythologizing not subject to scientific explanation: prescriptive notions about language use; the conviction that the real object of the study of grammar is writing, thus equating knowledge of language with writing and reading skills; the view that certain varieties of a language or certain languages are esthetically, logically, or in some way superior to others; and so on.

Second—another part of our rationale—students should come to know that science is not exhausted by the topics covered in their standard high school science textbooks or by the list of names of departments in a college's faculty of science. Science is a way of forming questions about the world we occupy and seeking their answers, though it is not simply that; nor is science problem solving—except derivatively. For it is only insofar

as a measure of progress (in the way of depth of understanding as opposed to breadth of description) is made in accounting for some naturally bounded thing-in-nature that the rational pursuit of answers to coherent questions becomes science.

Third, linguistic inquiry ensures equal access to all students, for inquiry in this domain presents few barriers to people with physical handicaps, lends itself to cooperative inquiry by an entire classroom of students and/or by smaller subgroups, and is not on its surface gender-biased—of particular importance at overwhelmingly female institutions where prospective early childhood teachers are educated.

Also, in our experience, students who speak English as a second language are able to participate fully, relying on their native English-speaking classmates simply for grammaticality judgments, but not for scientific insights into the nature of language. For on the basis of very restricted triggering experiences, the science-forming capacity kicks in to do much of the work—often allowing quite interesting generalizations to be reached. Of course, linguistic inquiry need not be restricted either to English or to spoken language (as opposed to signed language), as it is in this initial stage of our work; in fact, the ideal situation would be to be able to take advantage of the linguistic diversity of a class of students to examine cross-linguistic, cross-dialectal, and cross-modular phenomena (see O'Neil 1991 for some discussion).

Since mathematics is not “concerned with the things we wish to discuss but rather with the way we wish to discuss them” (Newman 1956:1591–92), less demand is made on us to justify including set theory and logic in a linguistics course directly focused on scientific argumentation and its appreciation. However, our recent decision to include these branches of mathematics in the linguistics course has prompted some science educators to ask, “Why mathematics in a linguistics course?”

Our rationale for including mathematics is threefold.

First, together with number theory and the mathematics of three-dimensional visual space, we understand logic and sets to be the core of “natural,” more-or-less accessible mathematics—accessible for many of the same reasons given above for linguistics.

Second, there are cognitive and evolutionary relationships between language and numbers to motivate this inclusion, namely, the fact that “human language has the extremely unusual, possibly unique, property of discrete infinity [the concept of adding one, indefinitely], and the same is true of the human number faculty . . . , [it being] essentially an ‘abstrac-

tion' from human language, preserving the mechanism of discrete infinity and eliminating the other special features of language" (Chomsky 1988: 169).

Third—and most important—beyond this conceptual relationship between language and numbers, basic principles of set theory and logic can naturally be developed and directly linked to the linguistics course where relevant. For example, some aspects of the relationship between the structure of sentences and their meaning are naturally captured in set-theoretic terms. Consider the sentences in (2), in which only the definiteness of the subject noun phrases and their plurality vary. A natural and apparently sufficient way of expressing just the difference in meaning between universal and existential quantification (a function of whether a noun phrase is definite or indefinite), between plural and singular (cardinality of set intersection), as well as some of the constant aspects of the meaning of these sentences (predication as set inclusion and noun modification of a particular sort as set intersection), is shown in (2) (examples taken from Chomsky 1977: 48–51).

- (2) a. *The books we ordered arrived.* The intersection of the class of books  $B$  and the class of things we ordered  $O$  is included in the class of things that arrived  $A$ , taking the cardinality of the intersection  $B, O$  to be  $\geq 2$ .
- b. *The book we ordered arrived.* The intersection of the class of books  $B$  and the class of things we ordered  $O$  is included in the class of things that arrived  $A$ , taking the cardinality of the intersection  $B, O$  to be  $= 1$ .
- c. *Some books we ordered arrived.* There exists a class of books  $K$  included in the intersection of the class of books  $B$  and the class of things we ordered  $O$ , which is itself included in the class of things that arrived  $A$ , taking the cardinality of  $K$  to be  $\geq 2$ .
- d. *A book we ordered arrived.* There exists a class of books  $K$  included in the intersection of the class of books  $B$  and the class of things we ordered  $O$ , which is itself included in the class of things that arrived  $A$ , taking the cardinality of  $K$  to be  $= 1$ .

Complex relationships of this sort, between the syntactic structure of sentences and their meaning expressed in basic mathematical terms (through symbolic logic, numbers, and sets), can thus be one focus of a linguistic inquiry course and can also form one way of assessing the students' depth of understanding of one or another aspect of the material.

We turn next to a description and discussion of some of the materials that we have developed and their effect, the latter being largely based on our work in the schools.

#### 4 Curriculum Construction

The linguistics lessons that we have developed, and that we continue to develop in our Wheelock College course, take a very simple form: we ask students to attend closely to apparently uncomplicated facts about the language they speak, in this case English (although, as suggested above, there is no doubt that similar lessons could be developed for any language). In our preliminary, after-school sessions, we tried a number of phenomena out to see if they "worked," by which we mean that the phenomena brought students to understand that there were questions about their linguistic world whose answers they thought they knew but then realized that they did not know, which realization "induce[d in them] the wish to know the answer to some of these questions" (Bromberger 1992: 1–2, once again). And we also mean that a certain depth of explanation of the phenomenon seemed possible as opposed to a merely descriptive organization of the data.

Thus, we rejected potentially interesting problems either because their solutions could not possibly reach beyond simple description in principle, or simply because of the limited classroom time available to us. For example, the problems that are raised by tag questions and yes-no questions (with their related *do*-support complication) led us to drop questions about these and related phenomena for the latter reason, and also because they appeared to be too dependent on traditional grammatical terminology that students did not know or did not want to learn and that can be—as mentioned above—in tension with linguistic inquiry (Chomsky et al. 1985: 57–62).

When finished, the linguistics materials will consist of sets of intricately related problems and some proposed solutions aimed toward building overt understanding of a general theory of linguistic knowledge, knowledge that is held tacitly by speakers of a language. The solutions to the problem sets will, and some presently do, go far beyond a simple discussion and evaluation of proposed solutions, covering as well topics in the acquisition of language (both first and second languages) and language use. With this in mind, we give a couple of brief examples of linguistics problems, one from syntax and another from phonology. The latter is

now well worked out—both the problem and its solutions; the former is under development.

For example, a set of syntactic problems on reflexives could take off from data like those in (3). Examples (3a) and (3b) illustrate that reflexive pronouns in English cannot occur independently, but must have an antecedent from which they derive their reference; (3c) and (3d) show that this antecedent must stand in a certain structural relation to and must occur within a certain distance of the reflexive.

- (3) a. \**Herself* left.  
 b. *Emma* likes *herself*.  
 c. \**Herself* likes *Emma*.  
 d. \**Emma* said that John likes *herself*.

In the problems, the students' task is to come up with the notion of a dependent item and to make some approach to the constraints on where reflexives must occur vis-à-vis their antecedents. This entails construction of a scientific theory of reflexive distribution (part of what is referred to in linguistics as the binding theory), including recognition of the phenomenon to be explained, data collection, data classification, and hypothesis formation. Students then test their hypotheses by looking for counterexamples, and revise the hypotheses until they account for the data in as parsimonious a way as possible and in a way that makes accurate predictions.

Another set of problems is organized around the phonology of the plural forms of regular nouns in English: the distribution of the sounds /s/, /z/, and /iz/ with respect to the phonological characteristics of the final segment of the singular noun (e.g., *dog/z/*:*cat/s/*:*dish/iz/*). See the immediately following discussion, the problem set in appendix 1 (in its present form intended to be the first problem that students deal with prior to beginning the linguistics course), and the problem set in appendix 2 (which can be used either to assess the students' ability to generalize from an account of plurals to one of past tense forms in English or to deepen their understanding of the connections among the phenomena involved).

Problems of the sort described here are meant to build tightly on one another, an approach that contrasts quite sharply with the disconnected presentation of material in the usual science or mathematics course at this level.

Thus, asking students to generalize hypotheses to account for related linguistic phenomena offers a way of evaluating their understanding of linguistic inquiry. For example, from their hypothesis about the syntax of

reflexives, students can be asked to begin to make sense of the somewhat parallel data from the distribution of reciprocal pronouns, as in (4).

- (4) a. \**Each other* left.  
 b. *Emma and Alex* like *each other*.  
 c. \**Each other* likes *Emma and Alex*.  
 d. \**Emma and Alex* said that John likes *each other*.

And—looking forward to successfully having incorporated logic and set theory into our lessons—in evaluating the mathematics of the course, we will wish to know if the students can, for example, use their understanding of set theory and symbolic logic to capture certain essential aspects of the meaning of sentences as well as to formalize their linguistic hypotheses.

Initially then, and as a result of our after-school work at the secondary level, we settled on two phenomena that were themselves unrelated but each of which was itself interestingly related to other phenomena. On the basis of these two, we aimed to formulate coherent questions and to move toward tentative answers. These are the phenomena:

- The morphophonology of the plural forms of regular nouns: the distribution of /s/, /z/, and /iz/ with respect to the phonological characteristics of the final segment of the singular noun (e.g., *dog/z/*:*cat/s/*:*dish/iz/*).
- Certain constraints on contraction: the failure of *wanna*-contraction over a *wh*-trace and the blocking of *is*-contraction before a gap or trace (e.g., the ungrammaticality of \**Who do you wanna go?* and \**I wonder where Emma's today*, \**Emma's tall and Peter's too*, etc., vs. *Where do you wanna go?* and *I wonder when Emma's at home*, *Emma's tall and so's Peter*, etc.).

Answering the questions that arose once the students dug into the data enough to uncover the apparent mysteries involved meant *their* inventing a certain amount of terminology as needed, though in the lesson plans that were finally codified, more-or-less standard terminology (e.g., "voiced") was fastened on—one of the results of reducing freewheeling ideas to lesson plans to be used by real teachers with real students in real schools, in recognition of the constraints of a standard educational system (Honda and O'Neil 1988).

As suggested above, simple and natural extensions of the tentative answers to related questions offer a way of evaluating the students' understanding of the material. For example, once having collectively worked through to a solution of the morphophonology of plural forms of regular



nouns, we want to know whether students individually can figure out how the regular past tense morphophonology of verbs works. And having come up with an explanation for the constraints on *wanna*-contraction and *is*-contraction, can students generalize their knowledge of the phenomena to account for the constraint on *hafta*-contraction (see section 5)?

So starting with apparent mysteries (e.g., the fact that you really can't say *wanna* whenever you *wanna*), turning them into questions, and proceeding to offer tentative answers for these questions, we hoped to show that students working together can build a theory as they go—a theory that will undergo constant revision in the course of study as its empirical consequences become more detailed. Moreover, it is only by staying with a problem and pushing it through to some sort of resolution—a way of proceeding that is quite different from if not directly opposed to the helter-skelter pace of typical science lessons—that work of this sort can be done.

## 5 Curriculum Trial: E/Affect

In our pilot studies in the schools, we worked after hours with small groups (generally four or five students). Following a relaxed Socratic method, we worked through problems at whatever pace seemed appropriate: moving quickly when answers came easily, spending more time when phenomena demanded more of the students' attention. For example, in one hour-long session, a group of seventh graders worked through the plural formation problem from start to finish, beginning with a spelling rule ("Add *-s*, *-es*, *-ies*"), moving to an interim phonological account ("Add an /s/ or /z/ or /iz/ depending on how the word ends"), and eventually arriving at a set of ordered rules in which "how the [singular] word ends" was precisely specified. Along the way, they constructed the notion "sibilant," calling such sounds "sorta-like-s," and they discovered "voicebox vibration," or the contrast between what one student called "sharp, less vibrant" sounds and voiced sounds.

With a group of ninth graders, however, the discussion of plural formation extended into two sessions as students—on their own initiative—pursued the most parsimonious rule. They revised an interim hypothesis to refer to the voicing of the appropriate plural ending, as well as to the voicing of the final sound of the singular noun. Much to our surprise, one of the students reinvented what used to be called alpha rules in phonology ( $\alpha$  a variable ranging over the values "+" and "-") by collapsing two statements about when to add /s/ and /z/ into a simpler statement, "Keep

[the] end sound going," or as the group later rephrased it, "Continue the voicebox vibration of the last sound." An argument over whether to label the rule an "s-sound rule" or an "end-sound rule" was resolved in favor of the latter during a third session when these ninth graders worked through regular past tense formation and noted the similarity of their solution to the one they had constructed for the plural. One of the students visualized a diagram that abstracted the phenomenon of voicing assimilation from the two accounts for the past tense and the plural, and made the proposal in (5).

- (5) Put this hypothesis in a diagram. You could have a bigger circle being "continue the voicebox vibration of the last sound," and then off of it you could have the S-ending, D-ending, etc., etc., etc.

Our pilot studies indicated the farthest reaches of "success" in engaging students in scientific inquiry into their own language. "Freewheeling" and "open-ended" accurately describe the nature of the pilot study sessions. In part, this is one sort of success: pursuing data and students' ideas about data in a variety of ways in order to construct an explanation of a phenomenon.

Another sort of success that came out of these pilot sessions involved the students' teaching us better ways of presenting the material as they worked it out among themselves. For example, when one student was having difficulty distinguishing word-final /s/ and /z/, as in *rock* and *bugs*, another student suggested that she put the words in a phrase with a vowel following (e.g., *rocks on the floor* vs. *bugs on the floor*) in order to bring out the voicing contrast to its fullest, intuitively recognizing that in citation form the /z/ of *bugs* does shade off into /s/ as the voice shuts down. This was a lesson for us on how to better help the students deal with their observations, one that we later built into the lesson plans.

Unconstrained by long-term curriculum demands, by large classes, or by the daily demands of a forty-five minute class period, with time taken for attendance and by intermittent announcements over the loudspeaker system—the real conditions of the school day—we were free in these after-school sessions to engage students in framing problems on the basis of puzzling over observations, gathering relevant data, organizing and abstracting from the data, learning, naming, and using linguistic concepts to account for data, formulating hypotheses, testing them by first imagining what a counterexample would look like and then searching for disconfirming evidence, and—if necessary—reformulating or rejecting hypotheses.

And the questions did indeed engage students. In both our pilot studies and regular classroom sessions, the teachers we worked with were impressed by the eagerness with which their students pursued solutions to the problems. One seventh-grade science teacher who observed a pilot session noted with some surprise the active participation of two students neither of whom did well in school. When asked to evaluate the linguistics sessions, one of these students said, "It's not really hard, but it makes you think."

Another measure of success was the new intellectual confidence that the students showed as they moved from the linguistics lessons to other subjects in the science curriculum. For example, after completing the linguistics lessons in regular seventh-grade science classes, students began a new unit on weight and density. The science teacher noted that the seventh graders used the methods of inquiry and the relevant terminology of the linguistics lessons. When asked to record their observations of things that sink and things that float, several students noticed there was no space available on their worksheets for their hypotheses. Students spontaneously suggested the need to make a hypothesis, test it, and then try to "find something that doesn't follow our hypothesis"—that is, a counterexample.

The transition to working with whole classes of students required us to consider the demands of and on classroom teachers as well as students. For us, an important question was whether this transition could be made while preserving the intellectual focus of the pilot-study sessions. The answer to this question is a qualified yes, largely because of the difficulties of fully involving the regular classroom teachers, who felt burdened by teaching yet another subject about which they knew very little and by being asked to adopt an unorthodox and thus—for them—uncomfortable teaching style. And so—at the risk of undercutting the more open classroom style that we wanted to cultivate—the need arose for us to provide carefully worked out lesson plans with standardized terminology, a set of likely hypotheses, worksheets to be done in class and for homework, and a written test to evaluate students.

Even in the regular classes, however, students were easily engaged in puzzling over linguistic phenomena, phenomena so familiar that they seemed initially unproblematic. For example, students were introduced to plural formation via the fiction of a Martian scientist who is learning English and who wants to make plurals so that she sounds like an ordinary English-speaking person (see appendix 1). In response to the question of what the Martian scientist must discover about how plurals are formed in

speech, most students usually stated a standard spelling rule. And when *wanna-* and *is-*contraction were first introduced, students agreed that "everyone slurs words 'cause it's easier." Just as students shared the same schooled "answer" to questions about plural noun formation, so they also shared a certain schooled confusion about contraction (Is it correct? If so, when is it correct? etc.) as well as the naive belief that, as one student said, "You can say *wanna* whenever you *wanna*."

Nor were the teachers initially any more at ease with the material. For example, one teacher denied ever being so sloppy as to say *wanna*, thus setting herself up for her *wanna*'s to be successfully hunted down by her students. Others rejected sentences like (6)

(6) Who do you wanna see?

because of its violation of the *who* ~ *whom* distinction.

It requires little effort to reveal the shortcomings of these initial normative notions or naive conceptions of the phenomena under consideration, and thus to motivate the real questions and the pursuit of their answers. And given arrays of data, students were generally able to give clear judgments about the acceptability of forms. Here we found that the seventh graders were quicker and surer of their judgments, with entire classes booing or shouting out, "No way!" in response to an unacceptable form. On the other hand, the eleventh- and twelfth-grade students were very hesitant when faced with the linguist's query, "Does this sound okay? What's your gut reaction?" This is likely due to schooling—that is, to their having learned prescriptive rules that call into question ordinary patterns of language use. As one twelfth grader said, "If you're in a business atmosphere, you're not gonna use the word *wanna*."

But there is another effect of schooling that might explain the older students' hesitancy: their judgments are rarely sought or valued, and are certainly never an input to inquiry. And so they were afraid and unsure in the face of our questions, as if they were being set up for a trick or potential embarrassment. For example, when we interviewed the older students after completing the unit, one student complained that we knew all along what the answer was, and rather than giving it to them in the way they were used to, we had made them work for it. Another student believed that we were using the class to get answers to problems that we couldn't solve ourselves in order to become rich and famous, a standard suspicion that dogs anthropologists in the field. In these respects, the college students we have worked with differ not at all from the high school students, for the former are the descendants of the latter, the difference

being that they have suffered even longer in the standard educational system.

Although discussion was more constrained by the fact of the lesson plans, working with regular classes of students had certain advantages. For one, more people are likely to come up with more ideas. Under certain conditions, this can be a difficulty as well. For example, on the way to an explanation of the constraint on *wanna*-contraction in terms of its being blocked by a *wh*-trace falling between *want* and *to*, two seventh-grade students came up with the beginnings of a simple equi-NP solution (7).

(7) When someone is talking to you about yourself, it is OK [to contract]. When someone is talking to you about someone else, it is not OK [to contract].

For they had noticed that the question (8),

(8) Where do you wanna go? (← Where do you want to go?)

for example, can be answered with something like (9),

(9) I wanna go to Club Med.

in which the “wanter” and the “goer” are the same, but that the ungrammatical (10)

(10) Who do you \*wanna go? (← Who do you want to go?)

can only be answered with something like (11),

(11) I want Jim to go.

in which the “wanter” is different from the “goer.” Since the lesson plans had not foreseen their entirely reasonable hypothesis—one that did not use the notion “*wh*-trace,” but at this early stage of discussion was perfectly equivalent in its coverage of the data to an account based on traces—the science teacher dismissed it, declaring that it was “overly complicated.” And by not running the students’ hypothesis through, the teacher clearly had not gotten the point of the enterprise: that to teach inquiry is to engage in inquiry. Thus, a perfect opportunity for trying to decide between two seemingly equivalent explanations was lost. We had hoped that providing a set of options would increase the teacher’s confidence in dealing with unfamiliar material, but instead, the lesson plans led the teacher to think that there was in fact a closed set of possible answers for quite open-ended questions. By our creating lesson plans that met the teacher’s needs, the teacher was led to not meeting the students’ needs.

There is the potential for a similar sort of problem to arise in the evaluation of individual students. For example, we developed the test item in (12) to assess students’ understanding of the contraction phenomena.<sup>6</sup>

(12) The Martian scientist hears two students having the following conversation:

Student A: Where do you *have to* go tonight?

Student B: What?

Student A: I said, Where do you *hafta* go tonight?

Student B: Oh, I *hafta* go to the mall tonight.

The Martian scientist discovers *hafta*-contraction. It seems to her that you can always contract *have to* to *hafta*. The next day she goes into a sub shop and she asks the following question:

\*What kinds of subs do you *hafta* go?

The person at the counter says, “You must be a Martian because an ordinary speaker of English wouldn’t say that! That sounds really weird. You should say,

What kinds of subs do you *have to* go?”

Write a hypothesis that explains why the Martian scientist cannot contract *have to* to *hafta* in sentences like this one. Give examples that show how your hypothesis works.

Since the lessons focused on the role of *wh*-traces in accounting for *wanna*-contraction and *is*-contraction, we expected the students to make use of this notion to account for *hafta*-contraction. And indeed, many students did. For example, one seventh grader wrote the answer shown in (13).

(13) She can’t contract *have* and *to* if there is a word or reference point [i.e., a *wh*-trace, represented as ·] in between *have* and *to*. Otherwise it’s OK.

Ex. 1—Where do you have to go · tonight?

Ex. 2—What kinds of subs do you have · to go?

Given the thrust of the lessons, this answer was the “correct” one. However, other students gave semantically based accounts. For example, an eleventh-grade student wrote the answer in (14).

(14) When *have* means possession, you can’t contract it in these sentences.

As with the equi-NP solution offered for *wanna*-contraction, this student's semantically based account is equivalent to the syntactic one, given the data presented.

Another seventh grader gave an answer almost identical to (13), but with the examples in (15).

(15) Do you have *a person* to go to the store? Do you have *dogs* to sell?

And when asked in an interview to explain these examples, the student said,

(16) Both of them have a word in between them so you can't contract them 'cause it wouldn't sound right. If I could it would sound like, Do you hafta a person to go to the store? Do you hafta dogs to sell? And it wouldn't sound right to an ordinary person.

The student also showed the interviewer how the *wh*-trace blocked contraction in the question, *What kinds of subs do you have to go?* However, when asked to explain when contraction is possible, this same student gave the semantically based account in (17).

(17) You *can* contract it . . . when you're talking about what you do, what you hafta do—what you *must* do. And it's OK to say it if you're saying something like, I hafta go to the store. I hafta get that book. I hafta get that dress. . . . What kinds of subs do you hafta go! Well, you can't say it there because you're talking about . . . what somebody *has*. And—yeah, what somebody has.

This student apparently had two explanations of *hafta*-contraction in mind. What should have been done—a step not taken in the context of the posttest interview—was to push the student to try to choose between the two by thinking through what counterexamples to the hypotheses would look like and by then trying to expand the set of data to include such counterexamples as those given in (18), say, in which *have to* has the meaning 'must', but where contraction is not always possible.

- (18) a. I have only to ask and I get what I want.  
b. He hadda go home yesterday, and he hasta go home today, but yet I don't mind his/him having to go home all the time.

As with the lesson plans, it is difficult to anticipate all answers consistent with the data, nor, as we found, is it desirable—even on a test. For this closes off opportunities to fully develop inquiry.

## 6 Conclusion

There are two ways to deal with problems of the sort raised immediately above. The classic way is to try to build teacher-proof materials that provide detailed roadmaps covering every possible contingency. This apparently simple solution is demeaning of teachers and unrealistic; for when the material is easily "accessible" and its explanations relatively open, there is the strong possibility of a student's coming up with a reasonable alternative hypothesis at any time.

The right thing to do, and the hard thing, is to educate teachers to the scientific style. The problems that we encountered in the science classroom had little to do with linguistics or with the students, and very much to do with the fact that the science teachers were not themselves comfortable pursuing rational inquiry and taking the classroom risks that this involves: participating *with* students in the scientific enterprise, respecting the students' ideas, questioning their own, and admitting the limits of their own understanding, a matter to which we have now begun to turn our attention. But that brings us to the other, unfinished part of our story, one that we will not be able to tell until our work at Wheelock College has developed beyond its present, formative stages.

### Appendix 1: Plural Formation

A scientist from Mars has just arrived in the Boston area. The Martian scientist is learning to speak English, and she wants very much to sound like an ordinary speaker of English. Right now, the Martian scientist is having problems making plurals. *Plurals* are used when we talk about more than one of something. For example, the plural of cat is cats, and the plural of day is days. The Martian scientist does not know how to pronounce plurals correctly.

1. The Martian scientist listened carefully to English speakers' pronunciation of some plurals. She noticed that the plural endings sounded like the last sound in the word buzz. For example, say the following sentences aloud. Concentrate on the sound of the plural endings of the underlined words.

There are bugs on this plant.

The pears are rotten.

There are two birds in the sky.

On the basis of such data, the Martian scientist made up a simple hypothesis: *Add a Z sound to a word to make it plural*. If the Martian scientist follows this hypothesis to make plurals for the words below (and similar words), will she sound like us? Why or why not?

pig      rat      judge      rock  
lunch      cloud      shape      star

2. The Martian scientist heard someone say the sentences shown below, and noticed differences in the way the plural endings of the underlined words sound. Say the sentences aloud. Concentrate on how the plural endings of the underlined words sound.

All of the spoons and cups and dishes are on the table.  
There are goats and horses and cows on the farm.

Some of the plural endings sound the same. Which of the underlined words have plural endings that sound the same?

3. Say the plurals for the following words aloud. Listen to how the plural endings sound.

graph    myth    wish    lunch    rock    shape  
rib      room    snake    star    tree    dove  
cloud    law    kiss    watch    lie    breeze  
box      bus    rat    bell    judge    pig  
toe      bush    hen    fuse    day    crew

Put the words into groups according to how their plural endings sound.

4. Look at your answers to problems #2 and #3. Think about what your work shows about how we make plurals. Formulate a simple hypothesis that will help the Martian scientist say plurals so that she sounds like any ordinary speaker of English. (Hint: Say the words in each group without adding their plural endings. Listen to the final sound of each word.)

5. If the Martian scientist follows your hypothesis, will she be able to make plurals that sound "right"? Why or why not?

## Appendix 2: Past Tense Formation

The Martian scientist has come to understand many things about the English language. But now she is having problems making the simple past tense for words. The *simple past tense* is used when we talk about something that has already happened. For example, the simple past tense of kick is kicked, and the simple past tense of smile is smiled. The Martian scientist does not know how to form the simple past tense.

1. The Martian scientist listened carefully to English speakers' pronunciation of past tense forms, and heard the sentences shown below. She noticed differences in the way the past tense endings of the words sound. Say the sentences to yourself. Concentrate on the sound of the past tense endings of the words.

He cried and stomped his feet, and sounded awfully upset.  
She jumped up, climbed a tree, and waited at the top.

First put the underlined words into groups according to the sound of their past tense endings. Then think of a way to write the *sound* of the past tense endings, and label the groups.

2. Say the simple past tense of the following words to yourself. Listen to how the past tense endings sound.

walk    rob    kiss    knead  
shout    flip    treat    laugh  
play    raid    buzz    hug

Put these words into groups according to how their past tense endings sound.

3. Look at your answers to #1 and #2. Think about what the data show about how we make the simple past tense. Formulate a hypothesis that will help the Martian scientist say the past tense of words so that she sounds like a native speaker of English. (Hint: Think of how the words in each group sound without their past tense endings.)

4. If the Martian scientist uses your hypothesis, will she be able to pronounce the past tense of words so that she sounds just like a native speaker of English? Why or why not?

## Notes

This paper began as our presentation to the January 1991 Linguistic Society of America Meeting workshop entitled "Linguistics in the School Curriculum," the workshop itself leading to the Society's establishing a Committee on Linguistics in the School Curriculum. Then in April 1991, at a New York Academy of Sciences workshop on historical linguistics, O'Neil's remark that a lot of traditional beliefs and current foolishness about language are a result of a general low level of linguistic literacy resulted in our 23 September 1991 colloquium at the Academy: "Constructing and Evaluating Theories Using Linguistics in the School Science Curriculum," an expanded version of which (Honda and O'Neil, to appear) will be published in Otero, in press. The present paper is a much expanded and somewhat differently revised version of the Academy presentation, the result of our working with, adapting, and expanding these same materials and ideas for a course on bilingualism and language acquisition at Wheelock College (Boston).

Some of the material in this paper is taken from "Triggering Scientific Thinking through Linguistic Inquiry" (M. Kamii and W. O'Neil, proposed Co-Directors), a proposal recently submitted to the Undergraduate Curriculum and Course Development unit of the National Science Foundation. For their comments and help in preparing the proposal and thus this paper as well (at least in part), we wish to thank S. Glick, M. Kamii, and P. Willott, all of Wheelock College. They are, of course, not responsible for the material in its present setting.

1. Another reason for trying to trigger the Wheelock students' science-forming capacity through linguistic inquiry follows from the fact that at the College, human development majors account for approximately 80 percent of the undergraduate liberal arts majors; thus, some understanding of linguistics as well as of first and second language acquisition is necessary to their proper education and preparation for teaching young children, in particular for the large Life Span Development subset of these majors.

We have also used the general approach developed in these lessons in our ongoing work (1985-) with Nicaraguan-English-speaking teachers in that country's bilingual-bicultural education program, mainly as a way of having teachers understand and appreciate the integrity of the variety of English they speak (see O'Neil 1991).

2. For discussion of the notion "science-forming capacity" (Peirce's "abduction," more or less), see Peirce 1957, Chomsky 1968: 78-79, 1980: 139-40, 1988: 156-59, O'Neil 1990. For the possible relevance of this notion to science education, see Preece 1984 and Sebastia 1989; for an opposing, Piagetian view, see Gil-Perez and Carrascosa 1990.

3. We do not address the prior question of "Why science education?" since its answers are many and various. Note, however, that we do not subscribe to the notion that a science education is necessary in the late 20th century so that a citizenry can vote in an informed way on issues that are increasingly scientific in nature; that more and more the demands of the jobs available in this country are also scientific in nature; and so on. For in a democracy of the type that prevails in the United States and increasingly in the rest of the world, a citizenry is not offered the opportunity of making any decisions of significance and certainly not decisions of a scientific or technical nature. And the cant that a good science education is going to lead to a good job is simply a way to cover up the extreme social and economic disarray that the United States finds itself in.

If anything, a science education conducted in the way we envision it would undercut the scientism that exists in the society by bringing students to an understanding of the nature of scientific explanations: their limits and tentativeness, and not simply their elegance and beauty.

For a discussion of "why" questions, of some of the linguistic and interpretive problems they raise, and of questions in the philosophy of science central to our work, see Bromberger 1987, reprinted in Bromberger 1992 along with other essays relevant to our work.

4. Another aspect of the physical world that somewhat parallels linguistics in this respect is the explanation of why some things float and others sink. Together with other workers at Harvard's Educational Technology Center, we also developed a

low-tech floating-sinking part for the unit, lessons that played off of students' beliefs in the importance of weight to the phenomenon and subsequently pushed this along to a weight-for-size formulation of the notion "density."

5. For some discussion of the sorts of questions about water that continue to baffle scientists, see Amato 1992.

6. About the nature of the testing that we did: the high school students easily recognized that the multiple choice format that they were used to was not relevant. For example, we noted the interchange in (i).

(i) Student A: Is this a multiple choice test?

Student B: It couldn't be—that wouldn't make sense for the stuff we've been doing.

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