LINGUISTIC INQUIRY IN THE SCIENCE CLASSROOM:

"It *is* science, but it's not like a science problem in a book"

by

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in a domain. I propose a hypothesis about the relationship between metaconceptual knowledge about scientific inquiry and successful learning of the scientist's theories, and outline a controlled experiment that would test the proposed relationship. I then consider other results of this study, including anecdotal evidence that the seventh graders showed cross-domain transfer of some of the metaconceptual points of the linguistics lessons. I close the thesis with some reflections about the place of the scientific study of knowledge of language in education.

Chapter 2

The Theory-Building Experience: Investigating Knowledge of Language

Assuming that Chomsky (1987, 1988, 1993) is correct that part of the human biological endowment is the capacity to engage in scientific inquiry, the challenge for science educators is to find the best mix of pedagogical materials to make this implicit knowledge explicit and to enable students to pursue empirical work in a variety of domains of inquiry. Since "we come to understand [the scientific enterprise] more fully as inquiry and understanding progress" (Chomsky, 1987, p. 8), engaging in theory construction seems an appropriate experience for developing the science-forming capacity in young people. Creating opportunities for constructing and evaluating explanations for natural phenomena means tapping into areas where students have adequate domain-specific knowledge.

The present study in part explores whether secondary school students' conceptions of the nature of scientific knowledge and its acquisition can be changed given experience in scientific inquiry. In order to address this question, a two-week-long instructional unit in theory-building was developed which involves students in investigating linguistic phenomena, and thinking about the inquiry process (Evans, Honda, & O'Neil, 1987). Prior to and following instruction, students' understanding of the nature of scientific inquiry is assessed in the context of constructing and evaluating an explanation for some linguistic data, as well as in a domain-independent context, using the clinical interview method.

I begin this chapter with a brief overview of the nature of linguistic inquiry and the reasons why language is a suitable domain for secondary

students to investigate. Next, I discuss other efforts to promote scientific inquiry using linguistics in the primary and secondary schools. A review of selected curricula reveals the depth of linguistic inquiry possible with children in the primary and secondary grades, as well as the kinds of linguistic phenomena that are most compatible with the theory-building instructional approach to inquiry described in Chapter 1. I then describe the instructional unit and assessment measures used in this study.

Knowledge of Language as the Domain of Scientific Inquiry

Among other things, linguists seek to explain what a person knows when she or he knows a language. Certainly, part of knowing a language means knowing the labels for concepts that are meaningful to the particular culture in which the language is used, where a label may be a word, something less than a word (e.g., the regular noun plural suffix), or something more than a word (O'Neil, 1988).

Knowing a language also means knowing the rule system of that particular language. Evidence for this comes from a speaker's ability to use and understand her or his language, and to provide judgments about linguistic forms. For example, a speaker of English knows that it is fine to say:

(1) Frida put the flowers on the table, but not
*Frida flowers the table the on put.

(where an asterisk indicates that a sentence or word is not well-formed), recognizing that while both sentences contain English words, the words are not correctly structured in the second one.

Knowledge of the rules for arranging and interpreting sentences

extends far beyond word order to encompass the complex relationships among linguistic elements. For example, a speaker of English knows that the following question has two meanings, deriving from two different structures:

(2) Who do you want to visit?

The question-word <u>who</u> may be interpreted as either the subject or the object of <u>to visit</u>, as recasting (2) into its parallel 'surprise questions' reveals:

(3) You want <u>who</u> to visit? (subject of <u>to visit</u>)
You want to visit <u>who</u>? (object of <u>to visit</u>)

Thus, (2) is ambiguous because of its structural ambiguity, a fact which a speaker of English implicitly understands simply by virtue of knowing English.

Since the system of rules is stored in the brain and cannot be observed directly, speaker judgments of this sort provide much of the data of linguistics. Constructing theories to explain the nature of this knowledge, how it is acquired, and how it is used constitutes the scientific study of our knowledge of language (Chomsky, 1986).

<u>Using Linguistics to Promote Scientific Inquiry</u>

Students are often introduced to science in domains where their experience is impoverished and/or where their commonsense understanding is strikingly at odds with things in nature. Very little inquiry is possible or easily motivated conceptually when the problems of science seem--from a commonsense point of view--quite unproblematic to students.

Examining one's own language, however, can immediately uncover problems to be investigated. For example, in ordinary speech, speakers of English can contract <u>have to</u> to <u>hafta</u>, as in:

(4) I have to go to the mall tonight.

I hafta go to the mall tonight.

Given the frequency with which hafta-contraction occurs in casual conversation, it would be reasonable to assume the null hypothesis: there are no constraints on hafta-contraction. However, this is not the case, as shown by:

(5) What kind of subs do you have to go?

*What kind of subs do you hafta go?

Why is this so? Apparent mysteries of this sort--in which the null hypothesis fails--can readily be turned into problems to be investigated.

Moreover, the accessibility and familiarity of this kind of data means that all students can easily participate in data collection (e.g., Hale, 1975, 1981; O'Neil, 1969). According to Hale (1975), "The linguist or native speaker is in one respect better situated than other scientists. He does not need a lot of equipment to observe the data he studies--he has in his head knowledge of his own language; he can therefore observe his own speech" (p. 4). This feature makes linguistics particularly well-suited for the junior high school grades (when methods of scientific inquiry are typically introduced), since more traditional, laboratory-based instruction presents a number of obstacles. Many students, for example, have neither the physical coordination to conduct a laboratory experiment nor the mathematical skills necessary to measure and model laboratory test results (assuming they have access to such a setting at all). Also, "the fact that its data are accessed largely through introspection means that linguistics is fully accessible to students with physical limitations that might otherwise present a significant barrier to learning (blindness, gross motor impairment, etc.)" (Larson, n.d., p. 2).

Another striking aspect of having students investigate their knowledge of language is the conceptual accessibility of both the possible explanations for particular linguistic phenomena and the linguistic constructs necessary to formulate those explanations (e.g., O'Neil, 1969). For example, the work of Chomsky, Honda, O'Neil, and Unger (1985; discussed in detail below) reveals the ease with which seventh, ninth, and tenth graders learned about the characteristic of speech sounds called 'voicing', and the relative facility with which they made use of this construct in working out an account for plural formation based on the voicing of the final sound of the singular noun and its plural ending. One group of ninth and tenth grade students went even further, generalizing their plural formation hypothesis to account for past tense formation, a phenomenon which also involves voicing.

By using linguistics to promote scientific inquiry, students can come to know that science is not simply the subject matter covered in the standard school curriculum (that is, biology, chemistry and physics), but rather, science is a way of inquiring about things in nature and coming to understand them in a deep way (Honda & O'Neil, 1993). For although linguistic inquiry generally proceeds outside of a laboratory context, observing language and constructing theories about knowledge of language partially parallel methods in other sciences:

> In solar physics, for example, one wants to determine what processes are taking place in the interior of the sun. One cannot look into the sun, so one observes what can be observed (light emissions), and formulates a theory about what is taking place in the interior (fusion). Correspondingly, in linguistics, observing behavior at the periphery (speech) leads to the formulation of hypotheses concerning

processes and structures inside (language knowledge). (STAMPS, 1985, p. 9)

Finally, given that it is an unfamiliar subject to students and a relatively young science, linguistics is quite free of gender stereotypes--another attractive feature (Larson, n.d.).

The Appropriateness of Using Linguistics to This Study

Junior high and high school students come to the science classroom with their own beliefs about what scientific inquiry is. In this study, I investigate what these beliefs and conceptions are, whether they can be changed given experience constructing and evaluating theories, and whether there are age-related differences in initial and/or postinstruction conceptions. There are several reasons why it is particularly appropriate to the purposes of this study that the theory-building experience focus on knowledge of language.

First, all students speak at least one language natively and so have tacit knowledge of a language. Previous estimates of when a child reaches the mature state of language acquisition were conservatively set at around puberty (Lenneberg, 1967). However, recent research has shown that knowledge of native language phonology is reached within the first year of life (see Werker, 1989 for a review), and that much of native language syntax is in place before the age of three years (e.g., Crain, 1991). Clearly then, mature knowledge of a language is available to all normal secondary school students, and is, in effect, held constant across the ages considered in this study. This extensive experience with language can guide students' inquiry.

Second, research on the development of the ability to reflect on this tacit knowledge--called 'metalinguistic awareness'--shows the ability to

make judgments of syntactic well-formedness appearing around the age of seven (Gleitman, Gleitman, & Shipley, 1972); the ability to detect syntactic ambiguity appearing between eight and 12 years (Hirsh-Pasek, Gleitman, & Gleitman, 1978); and syllable awareness and phoneme awareness appearing in first grade children learning to read (Mann, 1986). These findings indicate that metalinguistic awareness is also available to secondary school students. It should be possible then to bring this awareness to bear on the scientific examination of language phenomena.

Third, naive theories about language phenomena seem to be fairly uniform across these ages. For example, Chomsky and her colleagues (1985) found that seventh, ninth, and tenth graders shared either the same naive theories or the same schooled "answers" about the phenomena of plural formation. When asked why speakers of English say bat/s/, boy/z/ and box/iz/, and not *bat/z/, *boy/s/ or *box/s/ (where slash marks enclose symbols representing pronunciation not spelling), students usually stated a spelling rule, like: "You add s, es, or ies." Although this rule does not account for the phenomenon of plural formation in speech, it provided a shared initial conception of the phenomenon which the students could then evaluate.

This seems quite special: students have uniform tacit knowledge of language, as well as uniform naive theories, and can rather easily be engaged in manipulating linguistic constructs in building an explanation for some data. This affords the rare opportunity to study age-related differences in a domain where theory construction and evaluation are conceptually accessible and where domain-specific knowledge and initial conceptions are controlled.

Previous Work Using Linguistics to Promote Inquiry

A number of curricula have been proposed for using linguistics to promote scientific inquiry in the primary and secondary school grades. In some of these curricula, linguistics is viewed as a discipline that integrates science and the humanities; for example, investigating linguistic phenomena may be used as a means to sharpen students' awareness of dialect variation in a social and historical context (Wolfram, Adger, & Detwyler, 1992), or to enhance their ability to analyze poetry and other language structures (Keyser, 1970). In other cases, the central focus of the curriculum is to develop students' understanding of the nature of scientific inquiry and knowledge (e.g., Chomsky, Honda, O'Neil, & Unger, 1985; Fabb, 1985; Hale, 1981; Honda & O'Neil 1988; Sproat, 1984; White Eagle, 1983). Common to all of these proposals is the active involvement of students in analyzing language data.

Several of these proposed curricula have been experimentally implemented at the primary school level (Fabb, 1985; Goodluck, 1991; Keyser, 1970; Wolfram et al., 1992) and the secondary school level (Chomsky et al., 1985; Honda & O'Neil, 1988; Kitzhaber, 1968; White Eagle, 1983). Of special relevance to this study are the ways in which these curricula were and were not successful at framing problems about linguistic phenomena, engaging students in constructing and evaluating internally consistent, generalizable explanations for data, and conveying to students the tentative and constructed nature of theories. Below I discuss the findings of four curricular efforts--two with primary school students and two with secondary school students--which contributed to shaping the instructional unit used in this study.

Keyser (1970)

Keyser (1970) suggested reformulating the study of grammar in primary and secondary schools from categorizing parts of speech and diagraming sentences to examining and formulating hypotheses about language. Arguing that "grammar can be viewed as an opportunity for students to learn how to engage in rational inquiry" (p. 40), Keyser outlined three lessons for primary school students which link the scientific study of particular English lexical phenomena to the study of poetry, sayings, and the like. Here I will discuss only the scientific investigation of the phenomena, which include: a restriction on verbs and the animacy of the nouns which verbs select (Lesson 1), the distinction between syntactic and semantic aspects of plurality of nouns (Lesson 2), and the distinction between active and stative adjectives (Lesson 3).

Lesson 1 examines restrictions on the animacy of the nouns which verbs select. For example, verbs like frighten and surprise require an animate object but are unrestricted with respect to the animacy of the subject. Thus you can say,

(6) The girl (or the table) frightened the boy, but not
*The girl (or the table) frightened the sofa.

On the other hand, verbs such as build and write require inanimate objects. Similar restrictions exist for some verbs and their subjects, with verbs like drink and sew requiring animate subjects but verbs like elapse and evaporate requiring inanimate subjects.

Students in a combined fourth and fifth grade class were asked to first name things that could be frightened (e.g., a deer, a mouse, a person), and then to name things which could never be frightened (e.g., a tree, a car, an idea, but not a brave man). Students were then asked to identify

what each list had in common. An immediate response was that all the things on the first list were living. However, this was easily shown to be false since a tree is alive but can not be frightened. Another hypothesis was that things which moved can be frightened; this was also rejected because of items like a car. It was finally suggested that the first list named "living things which move on their own accord," and the second list named either non-living things or living things which could not move of their own accord. Thus, with a minimum of guidance, students essentially defined the terms 'animate' and 'inanimate', replacing each list with a generalization. Because Keyser's report is so sketchy, it is difficult to know whether or not students reflected on the scientific importance of making a generalization about each list of words.

Although Keyser suggested ways to extend this investigation by comparing and contrasting frighten and other verbs to create classes of verbs, it does not seem that he did this with the students in the classroom trials. If this is true then the investigation was only trivially interesting. Students came to know more about object restrictions of the verb to frighten, but not about either verbs or object restrictions generally. The scientist, however, would pursue generalizing this research to see, for example, whether the concept animacy was useful to understanding restrictions of other kinds (e.g., on adjectives).

The other lessons also focus on categorizing and generalizing across lexical data. In Lesson 2, students learn that syntactic and semantic aspects of nouns do not always agree. A good example of this is the word scissors which requires plural forms of verbs in a sentence yet may be singular or plural in meaning. You can say,

(7) The scissors are on the table (meaning one or more pairs), but not

*The scissors is on the table.

By contrast, team is a noun which occurs syntactically with singular forms of verbs but may be interpreted as plural, according to Keyser. Extending and examining each of these types of nouns leads to the generalization that nouns like scissors and pants name objects which are made up of two parts that function as a unit; although they can have either singular or plural meaning, they require plural verbs. Collective nouns like team and class, on the other hand, require singular verbs, although they are units made up of individuals.

In Lesson 3, students distinguish adjectives which describe activities from those that describe states or conditions. Active adjectives can be used in imperative sentences (i.e., commands), such as,

(8) Be quiet.

Be polite.

Stative adjectives can not be so used, as in,

(9) *Be fat.

*Be hungry.

Investigating this contrast leads to the generalization that "active adjectives are about things which are under our control; stative adjectives are about things which are not under our control" (1970, p. 44).

These lexical phenomena are intriguing, and the problems they present are challenging for primary school students. Investigating them requires students to collect data, to create categories, and to formulate generalizations which differentiate the categories of data. Unlike Tobin and Capie's (1980b) laboratory experiments discussed in Chapter 1, these

problems actively engage students in constructing their own categories and generalizations (e.g., a definition of animacy). There is also the possibility of reformulating generalizations in the face of counterexamples. For example, in Lesson 3, the stative adjective healthy seems to be a counterexample to the generalization that such adjectives describe things which we do not control.[1]

Despite these positive points, I have two criticisms of these lessons. First, each lesson is a self-contained problem to be solved. The lessons do not build on one another by challenging students to consider and/or to extend what they know about other phenomena. Thus, it does not seem possible to generalize across lexical phenomena in an interesting fashion in Keyser's way (W. O'Neil, personal communication).[2] Second, the lessons do not include discussion of the inquiry process itself. Students are not asked to think about what they are doing and why they are doing it. For example, why should they be interested in finding words that share properties with a word like scissors, or in formulating a generalization about words like class and team?

In these lessons, data collection and hypothesis formation are not explicitly related to a process of constructing an understanding of a phenomenon or set of related phenomena. This is most likely explained by the fact that Keyser was not concerned solely with developing students'

[1] There are also dialect differences. According to Keyser, "the difference between individuals in their usage of these adjectives is useful in making the point that not every question has a black and white answer, a fact which is much in evidence in language" (p. 44)--an important point about inquiry in general.

[2] For example, in Lesson 1, the analysis of frighten is really about describing how the world is, that the world divides into things that can and cannot be frightened. This particular lexical-semantic analysis is not generalizable, and therefore is uninteresting to the linguist.

understanding of scientific inquiry when he created these lessons. Rather he was reconceptualizing the primary school English curriculum to involve investigating interesting linguistic phenomena.[3] Also, the lessons may be limited in their focus because they are intended for primary school students.

More recently, Fabb (1985) has worked with primary school students outside the English curriculum. It is to that work that I now turn.

Fabb (1985)

Attempting "to teach children the rules of language, by getting them to originate their own rules," Fabb (1985, p. 60) talked with small groups of 8- to 10-year-olds about language and language-related issues. In a Socratic style, Fabb pursued six themes with the children over a half-year period, including: (a) articulatory phonetics, (b) defining what a word is, (c) parts of speech, (d) phrase structure, (e) writing systems, and (f) signed language. What is clear from Fabb's detailed report of this work is the inherent interest of language and the accessibility of linguistic phenomena to primary school students. Here I will focus on the students' successes and failures at constructing an understanding of phenomena covered by the first four grammar-based themes.

The first theme Fabb explored with each group of students was articulatory phonetics. Cards showing the letters of the alphabet were used

[3] Aware of the potential discomfort this unfamiliar approach to the study of language might cause readers of Elementary English (where his paper appeared), Keyser noted, "An inevitable partner of this kind of inquiry...will be the expansion of the linguistic experience of both the student and the teacher. Thus a great many kinds of sentences which one would not normally encounter will arise in the course of discussion... Indeed, it is hoped that the creation of strange and unusual sentences will be encouraged" (1970, p. 40). But this may be exactly why linguistic inquiry is troublesome to most English educators, given their focus on the prescriptive and their rejection of the strange and the unusual.

to elicit from students a description of the manner in which the associated sounds are pronounced. This led to a discussion of the parts of the body used to produce speech, beginning with the jaw and the tongue. They were introduced to the voicebox and to the notion of voicing by feeling their throat vibrate when speaking as well as by observing how a vibrating rubber band gives rise to sound. Asked why the voicebox vibrates, one student answered, "The brain tells it to." Demonstrating how air movement causes the rubber band to vibrate introduced students to the role of the lungs in speech production. Other parts of the body were also identified as having a role, including the teeth, the lips, and the nose.

Following the discussion of manner and place of articulation, students were asked to draw diagrams showing all and only the body parts which are used for speaking. This exercise provided the opportunity to discuss the fact that a diagram should represent only information that is relevant to the particular task (e.g., a diagram of the parts of the body used in speech production need not contain blood vessels or the heart or the eye, as did some children's). On the basis of their diagrams, the students constructed a cardboard model of speech production, outlining a head with a movable jaw, lips, and tongue, attaching a pleated piece of paper for lungs, and stretching a rubber band across the vocal tract for the voicebox. The students went on to successfully use the model to demonstrate the production of individual speech sounds.

The second theme Fabb investigated was defining what a word is. Students were introduced to the notion 'definition'. They were asked to define words like chair and blackboard, which led to a discussion of features of definitions, such as identifying what something's purpose is, what something is made of, and so on. Students were then asked, "What is

a word?" Their responses ranged from "something that you say" to "a group of sounds put together that usually mean something." They also talked about what a word is not: "[ugh is] not a word because it doesn't make sense"; "[gagagoogoo] is not a word because it doesn't mean anything." The discussion of gagagoogoo raised the interesting question of whether babies have a language. Students seemed to agree baby language "doesn't mean anything"; "language must be understood by more than one person." Another child said, "If you can't write the words down it isn't a language," reflecting the common cultural belief that knowing a language means knowing how to read and write that language. The discussion of "What is a word?" successfully raised a number of general issues about language.

The third theme focused on investigating the construct 'part of speech'.[4] Growing out of a "What is a word?"-discussion about the meaning of a and the, the most productive work on parts of speech involved defining the category 'article' (or determiner). One particularly insightful student explained that the definite article the means "something or someone who is the only one of their own kind in a certain kind of space, for example I am one of the three kings in my three inch space." The same student defined my as "like the to me." Another student noted the generic meaning of a president in "a president of the U.S. should not..." and contrasted that with its meaning in "a president of the U.S. said that..." Students went on to make a table which summarized the differences between definite and indefinite articles.

According to Fabb, turning to a more general examination of parts of speech engaged students in thinking about why a particular word might be

[4] This contrasts with the traditional, non-inquiry-based grammar study task of categorizing words according to parts of speech.

categorized in a particular way. Students were asked to compare the definitions of parts of speech in several dictionaries, focusing on how the definitions differ, which are best and why, what is missing from the definitions, and so on. Students also invented their own categories and category labels, including: "add-ons" for articles, "phrase-mixer" for and, "cousin-verb" for then ("because it is like a verb but not a verb"), and "noise phrase" for eerrrr.

The fourth theme that Fabb developed was phrase structure. He began with a phrase construction game, asking students to make the longest sentence they possibly could using a set of word cards, each of which had a determiner, an adjective, or a noun on it. The set of cards also included one card with "Here is ___" written on it. After constructing lengthy noun phrases to fill in the blank, students were asked to group the cards according to grammatical category (building on their study of the previous theme) and to identify any limitations on how the words could be used in a "Here is"-sentence. Given the particular selection of word cards, students made the following generalizations: one and only one "add-on" (i.e., determiner) must be used, any number of adjectives could be used and in any order, and at least one noun must be used.[6]

Students went on to discuss other aspects of phrase structure and sentence structure. For example, they looked at animal, fish and bird names, which frequently have a modifier-noun structure. Asked why a hammerhead shark is called a hammerhead, and what a headhammer would be, they noticed that the modifier always precedes the noun. Fabb also extended the phrase construction game, asking students to expand the

[6] The selection of cards was constrained "so only these simple (and not fully accurate) generalizations about noun phrases could be discovered" (Fabb, 1985, p. 53).

set of word cards (e.g., to include verbs and prepositions). Later, students were asked to construct sentences without any verbs (which they could not do), and then sentences without any nouns (they proposed the imperative, Eat). Students also learned that syntactic tree structures can be used to show the relationship between words, on the analogy of a family tree.

In assessing his generally successful work with primary school children, Fabb identified what he believes is a significant problem that arose in relation to phrase structure parsing and the identification of grammatical categories. "The problem is that the status of these can not be deduced straightforwardly from the data" (1985, p. 60). For example, Fabb noted the difficulty in showing that a particular group of words forms a phrase. When he introduced the term 'noun phrase' in conjunction with the "Here is"-game, Fabb told students "the words were clustered together, and the most important word was the noun"; in doing so, he "fail[ed] to convey any justification for phrasal structure" (1985, p. 53). One student, for example, wrongly concluded that a group of words constituted a noun phrase if it ended with a noun; in making a tree diagram of the sentence I was walking and then I saw a dog, the student labeled then I saw a dog as a noun phrase because of this incorrect generalization. As Fabb pointed out, linguists justify a particular parsing by the test of movement: a phrasal constituent moves as a unit. Being a linguist, he suspects that the theoretical justification of movement as a test of phrasal constituency is far too complex for primary school students to understand.

However, it does not seem to me to be necessary to convey the theory behind movement as a test of constituency in order to more clearly motivate phrase structure. Evidence in support of my belief comes from Fabb's report of a student who noticed that "sentences can be said in different

ways...[as in] the boy is in the garden and in the garden there is a boy." According to Fabb, this statement reflects an intuitive understanding of transformational relationships. Thus, it appears that 'phrases move' is a conceptually accessible notion, one which students could probably construct for themselves with a carefully crafted set of data. At this pretheoretical level, phrase structure could be justified by its usefulness in analyzing and explaining particular syntactic phenomena.

Although Fabb also ponders the theoretical status of grammatical categories as mental representations, he was quite successful at leading students to understand the nature of categories. For example, he introduced students to the idea that an aspect of grammatical category is that words of the same category can substitute for one another in many situations. This idea of substitutability explains why one student's belief that an adjective was "sort of an add-on" is false; given the group's generalization about adjectives (i.e., any number of adjectives can be used in a noun phrase and in any order), an unacceptable sequence like the the car would be possible. At least one student clearly understood the idea of substitutability, arguing against another child's assertion that was and then both belong to the same "time"-category, because it is possible to say I was in the store but not I then in the store. Together with the previously discussed results of students' investigation of parts of speech, this indicates that constructing and evaluating grammatical categories is a conceptually accessible task for primary school students, even though justifying their status within linguistic theory may not be.

In discussing the theoretical status of parsing and grammatical categories, Fabb focused on the intellectual distance between his students' understanding and the linguist's theories:

> The problem we are faced with is this. (a) We can conduct discussions with children about simple issues in language, where they are able to form conclusions by themselves. (b) We want to teach children how to construct structural descriptions. However, issues of type (b) are too complex to be simply deduced in the classroom. (Fabb, 1985, p. 61)

It seems to me that the real problem here is identifying conceptually accessible ways of motivating the construction of ideas to explain linguistic phenomena. For although the linguist's theory-bound structural descriptions of language are clearly not accessible to primary school students (nor probably to secondary school students), it is just as clear from Fabb's work that primary school students can be engaged in linguistic inquiry at a pretheoretical level: making observations and collecting data, generalizing across data, finding counterexamples, defining categories, and constructing models to represent ideas. Thus, it does not seem necessary for students to understand the linguist's theories in order to construct reasoned understandings of linguistic phenomena.

Identifying conceptually accessible ways of motivating theory construction has been a major focus of other work developing linguistic curricula for secondary school students. I discuss this work below.

Chomsky et al. (1985)

The present study grows out of work begun with colleagues at the Educational Technology Center at the Harvard Graduate School of Education (Chomsky et al., 1985; Carey et al., 1988, 1989; STAMPS, 1985, 1986; NOS/STAMPS, 1988). Assuming the theory-building instructional approach discussed in Chapter 1, this work sought to impart a constructivist understanding of the nature of science to secondary school

students. Over the course of several years, curricular materials were developed to involve students directly in using scientific methods to construct and evaluate their own explanations for a variety of natural phenomena, including linguistic phenomena.[6]

In the early stages of this work, our goal was to identify linguistic phenomena that would be conceptually accessible for secondary school students to investigate (Chomsky et al. 1985). Working after school with groups of four or five students (one group of seventh graders and two groups of ninth and tenth graders), we piloted several phonological and syntactic constructions in English. Three of these constructions turned out to be quite successful: regular noun plural formation, want + to contraction (i.e., wanna), and x + is contraction (i.e., x's, where x is any word, e.g., She's an anarchist and so's he).

Noun plural formation. We began the pilot sessions with the problem of forming regular English noun plurals in speech. What must be explained is the distribution of the plural endings:

(10) /s/ as in: lips, bats, rocks, laughs, myths,...
/z/ as in: clubs, nerds, bugs, doves, pies,...
/iz/ as in: kisses, fezzes, judges, lashes,...

This problem requires students to generate and categorize data, and identify the conditions for the distribution of the three plural forms. In formulating an account for the data, students move from a list approach to an analysis of the final segment of the singular nouns and their plural

[6] We also successfully piloted lessons on floating and sinking objects, in which students develop their ideas about density, and on the nature of yeast (described in Chapter 1), in which students test and extend their understanding of 'living thing'. These lessons focus on theory-building in the context of laboratory experimentation (STAMPS, 1986; NOS/STAMPS, 1988).

forms. This involves generalizing across each category of data in order to abstract a shared phonological feature of those data, the relevant ones being 'voicing' (i.e., the presence or absence of vocal cord vibration) and 'sibilancy' (i.e., the hissing and hushing sounds of language).

The linguist/instructor introduced the plural construction by asking students for their judgment of an ill-formed plural, such as:

(11) *I saw five dog/s/.

Students' unanimous judgment that this was unacceptable immediately revealed the problem: How are plurals made? Students were then asked to figure out how to explain plural formation to a Martian. This they managed quite well. For example, in one hour-long session, seventh graders worked through the problem from start to finish, beginning with a spelling rule: "Add -s, -es, -ies," moving to an interim phonological account: "Add a /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.[7]

With a group of ninth and tenth graders, 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 amazement, one of the students collapsed separate statements about when to add /s/ and

[7] Formulating an explanation for these data required students to invent a certain amount of terminology, which they easily did as needed, indicating the accessibility of these particular linguistic constructs.

/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."[8] An argument over whether to name this the "end with s hypothesis" or the "end-sound hypothesis" was resolved in favor of the latter during a third session when the students 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 which abstracted the process of voicing assimilation from the two accounts for the past tense and the plural, and made the following proposal:

> 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.

Wanna-contraction and 's-contraction. We also piloted two constructions involving syntactic constraints on the contraction of lexical items, the first being the contraction of want to to wanna. For example, speakers of English generally contract want to in ordinary conversation, as in:

(12) Who do you want to speak to?
Who do you wanna speak to?

The problem arises from the puzzling fact that contraction is not always possible, as in:

(13) Who do you want to speak?
*Who do you wanna speak?

These facts are related to the nature of English question formation and the abstract positions in sentences to which question words are linked. In (12),

[8] In so doing, the student reinvented what are called 'alpha rules' in phonology (where alpha is a variable ranging over the values '+' and '-').

the question word is linked to a position following the second to, a fact that can be established by the structure of a full answer to the question and by the structure of the parallel surprise question, as in:

(14) I wanna speak to Godzilla.
You wanna speak to who?

In (13), the question word is linked to a position between want and to. This too can be established by answering the question and noting the surprise question form, as in:

(15) I want Godzilla to speak.
You want who to speak?

Question words are linked to a position in the sentence by what linguists call a 'wh-trace'. It is the location of the wh-trace that controls the contraction of want and to in these questions. If the wh-trace falls between want and to, then contraction is not possible. Thus, a purely abstract linguistic construct (i.e., one that is not phonologically realized in the speech stream) has the same physical effect as a word, as can be seen in (15) where wanna-contraction is blocked by Godzilla and who.[9]

The effect of unheard and/or unspoken elements is also illustrated in another phenomenon we piloted, x + is contraction. In English, is can usually be contracted onto the word that immediately precedes it, as in:

(16) Emma is tall and so is Peter.
Emma's tall and so's Peter.

[9] Within current linguistic theory, the position of a trace is assumed to be the result of the movement of a word or phrase from that position (e.g., a question word is moved to the front of a question, leaving behind a wh-trace). Here we assume simply that a relationship exists between a word or phrase and its trace, for it is far more complex to justify that a word or phrase has been moved than to motivate its relationship to a 'position of interpretation' or 'reference point', as we have called trace.

Here too, the null hypothesis is wrong: is can not always contract onto the word that precedes it, as shown by the contractibility of the first but not the second is in (17):

(17) Emma is tall and Peter is too.
Emma's tall and *Peter's too.

In English, repeated material can be deleted from the second of a pair of conjoined sentences. Linguists posit that the deleted material leaves a 'trace', a point of interpretation similar to the wh-trace of question words. In these sentences, the repeated material (tall) has been deleted from different positions, leaving a trace following Peter in (16) and one following is in (17). As in wanna-contraction, something that is not present in speech blocks contraction. If the trace directly follows is--as in (17), then is can not be contracted.

As can be seen in (18) and (19), the location of wh-trace (wh-t) also controls the contraction of is onto the preceding word.[10]

(18) I wonder what Emma is looking at wh-t.
I wonder what Emma's looking at wh-t.

(19) I wonder where Emma is wh-t today.
*I wonder where Emma's wh-t today.

Given this, the account of 's-contraction must also include the blocking effect of wh-trace immediately following is.

Each of these contraction problems requires students to generate data (i.e., judgments of contracted forms and the location of traces), make observations of these data, and abstract a condition blocking contraction. In

[10] These sentences are indirect questions; for example, (18) contains the question, What is Emma looking at? The wh-trace can be located using the methods discussed earlier, i.e., fully answering the question and/or asking a surprise question.

order to formulate an account for each of these phenomena, students must locate the position of traces and identify their effects. The effects of traces provide an interesting linguistic comparison to other abstract constructs posited by scientists, such as gravity.

In the pilot sessions, students were introduced to these contraction phenomena by means of a data sheet of uncontracted sentences. Asking students for their judgments of contracted forms immediately engaged students. For example, seventh graders were intrigued by their quick, clear judgments of the well-formedness of wanna in questions like (12) and (13), formulating the research question: "When do we use wanna?" Although they easily learned to interpret the location of the wh-traces, they were initially unable to coordinate this data with their judgment data. For example, one student suggested the easily falsified hypothesis: "When talking about something you're gonna do in the future." To focus their attention, the students were asked to compare the following and to think about when contraction is not allowed:[11]

(20) I want Bill to go.
Who do you want to win?
Where do you want to go?

All of the students agreed that wanna-contraction is not allowed in the first two cases. One of them then hypothesized, "When you got something between want and to you can't contract." Based on the data before them, the linguist/instructor defined what "something" meant and added to the hypothesis, "where "something" is a word or a position of interpretation." The group then turned to one student's judgment of (21), which seemed to

[11] Having stated the research question in terms of when contraction is allowed, students seemed to get stuck in their thinking, not imagining the possibility of a blocking constraint.

be a counterexample to the hypothesis:

(21) What do you want to win?

*What do you wanna win?

A lively discussion ensued in which the group determined that this was not a counterexample because the student was interpreting the question word between want and to, as if the surprise question was, You want what to win? This potential counterexample raised the issue of structural ambiguity (which the group had discussed during an earlier pilot session), and provided an interesting test of the hypothesis.

These seventh graders approached the problem of 's-contraction with equal enthusiasm. They quickly judged the acceptability of contracted forms for a set sentences which included both conjoined sentences with deleted material, such as (16) and (17), and indirect questions, such as (18) and (19). Beginning with the false proposal: "You only contract is after a noun," they then formulated an interim solution, correctly determining that for sentences like (16) and (17) "if tall is [restored] we can contract," but incorrectly observing that "if tall is not there we can not." They were then asked to consider sentences like (18) and (19), which contain indirect questions, and to interpret the position of the question words (i.e., the location of the wh-traces). Based on these new data, one student observed, "You can only contract if [the wh-trace]'s at the end of the sentence"; this was met with unanimous approval. With the linguist/instructor's help, the students discussed how to falsify the hypothesis and determined that a valid counterexample would be one where the wh-trace is not at the end of the sentence but where 's-contraction is allowed. The hypothesis was then easily falsified by lengthening a version of (18):

(22) I wonder what Emma is giving wh-t to Peter today.

I wonder what Emma's giving wh-t to Peter today.

After a long discussion of the location of the wh-traces in the data set, one of the students proposed a new hypothesis: "Can't contract if [the question word]'s interpreted right after is." The students decided this hypothesis was not general enough because it did not explain contraction in conjoined sentences like (16) and (17), where the interpreted word is not a question word. Two students then formulated the more general hypothesis: "Can't contract if the word being interpreted is interpreted right after is."

Investigating the plural (and the related past tense) construction and the contraction phenomena successfully engaged students in constructing and evaluating theories about their knowledge of language. Students understood the problems, generated the data, and made the necessary linguistic judgments easily. Working cooperatively and guided by the linguist/instructor, they formulated internally consistent accounts for sets of data, considered counterexamples, and revised their hypotheses as needed. They also generalized their understanding of linguistic constructs in order to relate phenomena which on the surface seem unrelated.[12] Clearly then, it is not necessary for students to know and operate within the linguist's theories in order to formulate interesting and fairly sophisticated explanations that make use of the linguist's constructs (e.g., phonological features and trace).

[12] The task of accounting for related phenomena offers a way of evaluating the students' understanding of the material. For example, having worked out an account of voicing assimilation in plural formation, students could be asked to explain past tense formation. Similarly, students could be challenged to generalize their knowledge of the effect of wh-traces in wanna-contraction to 's-contraction, or to the more similar hafta-contraction.

The teachers of the students we worked with were impressed by their students' eagerness to work through these problems. While there was a good deal of verbal interaction between the students and the linguist/instructor, there were also periods of silence when students seemed to be deep in thought. After observing a pilot session, a seventh grade science teacher noted with some surprise the active participation of two students neither of whom did well in school. Asked to evaluate the linguistics sessions, one of these students said, "It's not really hard, but it makes you think."[13]

Formation of yes/no questions and tag questions. We were least successful at involving students in theory construction using yes/no questions and tag questions; it is worth noting here why. A yes/no question is one which demands a "yes" or "no" answer, as in:

(23) Is Frida great?

Does Frida paint portraits?

In tag questions, a statement is questioned and the question is "tagged on" to that statement, as in:

(24) Frida is great, isn't she?

Frida paints portraits, doesn't she?

In our view, accounting for yes/no questions and the somewhat related tag questions seems too dependent on traditional grammatical terminology that

[13] Another success of these pilot sessions was that the students taught us better ways to present the material. For example, when one student was having a difficult time distinguishing word-final /s/ and /z/, as in rocks 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 when bugs is pronounced in isolation the /z/ becomes /s/ as the voice shuts off.

the students we worked with did not know (Chomsky et al., 1985). For example, describing the yes/no question data (the simpler of the two phenomena) involves identifying the type and location of the noun and verb forms, and the appearance of do forms; the need for grammatical terminology is apparent. The difficulty this posed is best illustrated by the fact that one student could not test the group's final hypothesis about yes/no question formation because she did not know what a verb was.[14]

Another more compelling reason to reject these two phenomena is that their explanation must account for the appearance of forms of do. The appearance of do forms is motivated by an analysis of underlying structure in which 'tense' is a syntactic element distinct from the verb (W. O'Neil, personal communication). Such an analysis is well beyond the reach of seventh graders (the target population). This means that only an ad hoc explanation in which forms of do simply "pop up" in these question constructions is possible; a satisfying explanation for why these forms appear is not conceptually accessible to most students, in violation of an important principle of the theory-building approach to instruction.

Carey et al. (1988), Honda and O'Neil (1988)

Having identified appropriately engaging and conceptually accessible linguistic phenomena, we then turned our attention to creating theory-building lessons which would involve secondary school students in reflecting on the process of constructing and evaluating explanations for the phenomena. We developed a week-long series of linguistics lessons, part of an innovative month-long unit on the nature of science and scientific inquiry (Honda & O'Neil, 1988 in NOS/STAMPS, 1988).

[14] Following on the work of Fabb (1985), constructing definitions of the parts of speech might have been a challenging and useful first task.

The linguistics lessons focus on the blocking effect of wh-trace first in wanna-contraction, and then in 's-contraction.[15] Throughout the lessons, inquiry-oriented vocabulary is used, including 'data', 'hypothesis', 'test', 'revise', and 'counterexample'. The lessons also introduce linguistic terminology, such as, 'reference point' for wh-trace. In addition to theory-building, the lessons incorporate a good deal of discussion of the following points about the nature of scientific inquiry:

- to formulate a hypothesis to explain a phenomenon, look for patterns in the data; if the phenomenon is similar to one you already understand, then try to generalize what you know;
- progress is made in explaining a phenomenon by formulating and testing a hypothesis, and evaluating the results;
- a hypothesis may need to be reformulated in order to provide the best possible explanation and coverage of data;
- searching for counterexamples is a way of further testing and developing a hypothesis.

The month-long unit was piloted in two seventh grade science classes (Carey et al., 1988). We found that the linguistics problems worked as well in whole classes as they had in the pilot sessions (Honda & O'Neil, 1993). Narrowing the 's-contraction problem to an investigation of data involving wh-trace made it seem more immediately similar to the phenomenon of wanna-contraction, and students were quite able to generalize the wh-trace construct. Working with whole classes of students had certain advantages over the small-group pilot sessions. For one, the liveliness of the small groups was multiplied in the larger setting. Working in pairs, students

[15] Given that we had only a week for the linguistic lessons, we did not include noun plural formation.

became quite competitive about formulating the best hypothesis.

Also, more students meant there often were more ideas to consider; unfortunately, this was also a disadvantage given the lesson plans. For example, on the way to an explanation of the constraint on wanna-contraction, two students came up with an interesting hypothesis:[16]

When someone is talking to you about yourself it is ok [to contract].

When someone is talking to you about someone else is not ok.

They had noticed that the question:

(25) Where do you wanna go?

could be answered with something like (26) in which the 'wanter' and the 'goer' are the same:

(26) I wanna go to Club Med.

They had also noticed that the ungrammatical question:

(27) *Who do you wanna go?

could only be answered with something like (28) in which the 'wanter' is different from the 'goer':

(28) I want Godzilla to go.

Since the lesson plans had not foreseen their entirely reasonable hypothesis--one that did not use wh-trace, but which was perfectly equivalent in its coverage of the data to an account based on wh-trace, the teacher dismissed it, declaring that it was "overly complicated." A perfect opportunity for trying to decide between two seemingly equivalent explanations was lost.

Unlike the pilot sessions which were led by a linguist, the pilot of the linguistics lessons involved the regular classroom teacher co-teaching with

[16] This is the beginning of a simple 'equi-NP' solution based on whether the subject of the two verbs is the same.

a research assistant from Harvard's Educational Technology Center. We had hoped that providing a set of options would increase the teacher's confidence in dealing with unfamiliar material, but instead, the lessons plans led the teacher to think that there was in fact a closed set of possible answers for quite open-ended questions.

The Instructional Experience in Linguistic Inquiry

The present study follows on our earlier linguistic work with secondary school students (Carey et al., 1988; Chomsky et al., 1985), and in part explores the effects of a longer instructional unit on students' conceptions of the nature of scientific inquiry.

Goal and Objectives

The goal of the two-week-long instructional experience is to introduce students to the constructivist view of scientific inquiry. Assuming the theory-building approach, the instructional unit was designed to meet this goal by engaging students in constructing and evaluating theories about their knowledge of language, and by involving them in reflecting on this process and the tentative nature of the explanations to which this process leads (Evans, Honda, & O'Neil, 1987).

The unit consists of nine lessons, each of which is meant to occupy one forty-five minute class session (see below for a detailed description of the linguistics lessons). The unit covers one phonological problem, noun plural formation, and two syntactic problems, wanna-contraction and 's-contraction. In order to move from descriptions of the data to constructing explanations for these phenomena, students must develop an understanding of particular linguistic constructs, such as voicing and wh-

trace (the latter referred to as 'reference point' in the lessons). The unit builds on the preinstruction written problem set and interview experiences, where the phenomenon of plural formation and the scientific study of language are first introduced and explored.

Throughout the unit, students investigate their implicit knowledge of language by examining their judgments about these linguistic phenomena.[17] Their judgments provide the impetus for engaging in scientific inquiry: framing problems on the basis of puzzling observations that violate naive beliefs, identifying and gathering relevant data, organizing and abstracting from the data, using linguistic constructs to account for data, formulating testable hypotheses, testing the hypotheses and evaluating the results, reformulating or rejecting hypotheses, and searching for disconfirming evidence. Although students work at a very superficial level with respect to the science of linguistics, they probe these phenomena to some depth of explanation.

Through this process of theory construction and evaluation, students are introduced to certain basic notions of scientific inquiry, including data, abstraction from data, hypothesis, experiment, counterexample, confirmation, falsification, and hypothesis revision. The lessons are designed to make these notions quite explicit. Discussion is directed towards helping students become conscious of the process of scientific inquiry in which they are engaging. There are also numerous written assignments which support and feed class discussions, and thus contribute to encouraging students to think on their own about the inquiry process.

[17] While the metalinguistic awareness needed to examine these particular phenomena is assumed to be available to students of the ages in this study, seeking their judgments serves to foster this awareness by engaging them in manipulating and reflecting on the phenomena.

Assessing Conceptions of Scientific Inquiry

While sharing many of the assessment goals of Carey et al.'s (1989) research discussed in Chapter 1, the present study differs significantly in its approach. This study attempts to assess students' understanding of the nature of scientific inquiry in the context of constructing and evaluating an explanation for some linguistic data, as well as outside the theory-building task in a domain-independent context (i.e., in the manner of Carey et al.'s clinical interviews).

In both contexts, the clinical interview method is used. Students are first given a linguistics problem set to work through. Later, in a separate session, students are interviewed individually. The interviews consist of two parts: (a) the Theory Construction Interview, which probes students' answers on the linguistics problem sets, and (b) the Nature of Scientific Inquiry Interview, which assesses students' understanding of the nature of scientific inquiry more generally.

The preinstruction Theory Construction Interview and the problem set it follows on are also designed to introduce students to the scientific study of language. The instructional unit assumes this experience.

The linguistics problem sets. The main intention of the problem sets is to involve students in linguistic inquiry. Students' written responses are later probed in the Theory Construction Interview, described below.

To avoid test-retest effects, the preinstruction problem set covers regular plural formation while the postinstruction problem set covers regular past tense formation. These phenomena are phonologically equivalent in that both present similarly structured forms (i.e., three endings of which one is syllabic: /s/, /z/, /iz/ for plurals; and /t/, /d/, /id/ for the past tense), and both can be explained in part in terms of the

assimilation of the final sound of the root word with a compatible suffix, where compatibility is determined by the shared phonological feature of voicing.

The linguistics problem sets are discussed further in Chapter 4, in the context of the Theory Construction Interview. The problem sets are included in Appendix A.

The Theory Construction Interview. In the first part of the clinical interview, students' answers on the linguistics problem sets are probed. This gives students an opportunity to further work through their account of the phenomenon, and to explain their work to the interviewer. The interview also provides the context for assessing students' understanding of theory construction and evaluation as they are involved in the inquiry process. Certain basic notions of scientific inquiry are probed, including: data, abstraction from data, hypothesis, counterexample, confirmation, falsification, and hypothesis revision.

The Theory Construction Interview and its results are discussed in detail in Chapter 4. The interview protocol is included in Appendix B.

The Nature of Scientific Inquiry Interview. The second part of the interview further probes students' understanding of the nature of theory construction and evaluation, but does so outside the theory-building context (i.e., in a domain-independent context). The Nature of Scientific Inquiry Interview includes selected and modified questions from the clinical interview used by Carey et al. (1989) to assess these issues more generally. Students are asked about the nature and purpose of hypotheses, the nature and purpose of experiments, and the nature and role of unexpected results.

The Nature of Scientific Inquiry Interview and its results are discussed in detail in Chapter 3. The interview protocol is included in

Appendix C.

The Linguistics Lessons

After the preinstruction assessment, students begin the linguistics lessons (Evans et al., 1987), the general outline of which is as follows: in Lessons 1 through 4, students are introduced to linguistic inquiry and investigate noun plural formation; in Lessons 5 through 7, students examine wanna-contraction; in Lessons 7 and 8, they extend their understanding of wh-trace (from wanna-contraction) to 's-contraction; and finally in Lesson 9, they end the two weeks of lessons with a review. The lesson plans are included in Appendix D.

Lesson 1 begins with students judging the grammaticality of scrambled English sentences. They also interpret the structural ambiguity of particular sentences (e.g., Visiting relatives can be boring). Why can these judgments and interpretations be made? Because all speakers of English have mental rules about the structure of their language. Comparing the ambiguous sentences to a visually ambiguous picture (which can be interpreted in two ways depending on what is perceived to be the figure as opposed to the ground) further highlights the role of the mind in making sense of these things. This introduces students to the scientific study of the mind--which can not be seen or touched--through language.

Next, the class returns to the plural formation problem, which was introduced in the preinstruction problem set. Putting themselves in the place of the Martian scientist, students begin to investigate plural formation by gathering data about plurals. On a worksheet to be done in class or as homework, students are given a set of singular nouns. They are asked to say each word and its plural, and then to sort the words into groups according to the sound of the plural endings.

Students begin Lesson 2 by identifying the three plural endings. To do so, they must differentiate spelling from sound, focusing on the latter. This leads them to formulate a descriptive rule about plural formation: You add /s/, /z/, and /iz/ to make a plural. Discussion of the rule's adequacy reveals that it does not explain the conditions for adding these endings. Thus, given this rule, the Martian scientist would not know how to apply it in order to sound like an ordinary English speaker. This leads to the discovery of a problem--an important part of science: When do you add /s/, /z/, and /iz/? To solve this problem, students begin looking for patterns in the data. The class discusses what kinds of patterns to look for in the singular word, rejecting the beginning and middle of the word on the basis of data which shows that words that are alike at those points have different plural endings, and choosing instead to focus on how the words end. Breaking a problem up into parts is often a useful way to solve it; this can be done with the plural problem. On a worksheet to be done in class or as homework, students are asked to identify what is similar about the final sounds of just the words that take the /iz/ plural ending.

In Lesson 3, students identify word-final sibilancy (referred to in the lessons as 'hissing or hushing') as the condition for adding the /iz/ ending, and they reformulate their initial hypothesis to include an explanatory rule for /iz/ plurals: If a word ends in a hissing or hushing sound, then add /iz/ to make it plural; otherwise add /s/ or /z/. The phenomenon of voicing is introduced. On an in-class worksheet, they are asked to identify the word-final feature shared by singular nouns taking /s/ and the feature shared by those taking /z/. This leads the class to formulate an explanatory rule for these plurals: If a word ends with a voiceless sound, add /s/; if a word ends with a voiced sound, add /z/. The students move on to test this hypothesis by

looking for counterexamples in the data; none are found. They return to the original problem and formulate an explanatory hypothesis for plural formation, bringing together the hypotheses for the syllabic and non-syllabic endings. For homework, students are asked to review the process of explaining plural formation. They are also asked to think about a more parsimonious way of stating the final hypothesis, and to identify any counterexamples.

At the start of Lesson 4, the class discusses the homework assignment, including apparent counterexamples that students have found. Students distinguish plurals which can not be structurally explained by a rule and are exceptions (e.g., deer-deer, in which the singular and plural forms are indistinct; child-children, in which the plural has an irregular ending), and those which can be structurally explained by the regular plural formation rule (e.g., loaf-loave/z/ and path-path/z/, in which the final sound of the singular form is first voiced, and then the voiced plural ending is assimilated). Exceptions do not show any regularity and do not require the hypothesis to be reformulated; they are simply added as a list to the hypothesis.

Next, the class returns to looking at the ways that words relate to one another syntactically, which was introduced in Lesson 1. When speakers of English are asked a question, they can answer the question and they can also ask a surprise question. The location of the answer in the full answer and the location of the question word in the surprise question provide data that the question word relates to a particular 'reference point' (i.e., a wh-trace). The rules all English speakers have in their minds about the structure of English allow them to make judgments about the location of the reference points of question words. On a worksheet to be done in-class or as

homework, students are asked to locate the reference points for question words in a set of questions.

Lesson 5 begins with students identifying the reference points for question words on the previous day's worksheet. Judgments about the location of reference points is one kind of data about the linguistic rule system at work in speakers' minds. Next, the class is introduced to wanna-contraction. Students are asked to use wanna in some sentences. It seems that speakers of English can always say wanna whenever they wanna! Students are asked orally to give their judgments about the acceptability of wanna-contraction for a set of questions, and to record their judgments on a datasheet. Their judgments show that wanna-contraction is not always possible, thus uncovering an interesting problem: When can we contract want and to? All of the questions on the datasheet have question words; question words have reference points. It may be that this information could be helpful in understanding the problem of wanna-contraction. In class or as homework, students are asked to locate the reference points for the question words in the questions on their datasheet.

Students begin Lesson 6 by briefly reviewing the work they have done in the last five lessons (i.e., the first week of the two-week-long unit). The class then returns to the problem of wanna-contraction. To begin to solve this problem, data needs to be gathered. Students go over the previous lesson's datasheet, identifying the location of the reference points of the question words. There are now two kinds of data available about the set of questions on the datasheet: students' wanna judgments, and their judgments about the location of the reference points of the question words. Students discuss what can be done with the data. They must look for a pattern or a relationship between the two kinds of data that might help

them formulate a hypothesis or possible explanation for the data. They work in pairs or small groups to formulate a hypothesis (which they write on a separate worksheet).

When the class comes back together, two hypotheses are proposed that are consistent with the data at hand: (1) If the reference point is at the end of the question, then you can contract want and to to wanna; and (2) If there's a reference point between want and to, then you can not contract want and to to wanna. Before testing the first hypothesis, the class reviews hypothesis testing (i.e., conducting an experiment).

It is clear to students that the first hypothesis covers the questions on the datasheet. By examining the hypothesis, the class decides that counterexamples to the hypothesis would take two forms: (a) a question where the reference point of the question word is not at the end of the question and wanna-contraction is allowed, and (b) a question where the reference point of the question word is at the end of the question and wanna-contraction is not allowed. With further discussion, students identify counterexamples of both types; these data do not seem to be exceptions (e.g., like irregular noun plurals) because many such counterexamples can be found.[18] Thus, the class must consider other hypotheses for wanna-contraction that will cover these data as well.

The class then tests the second hypothesis, examining the cases

[18] For example, a counterexample of type (a) can be gotten by taking questions in the data set where the wh-trace is at the end of the question and lengthening them, as in: Who do you want to speak to wh-t tomorrow afternoon? A counterexample of type (b) exists in the data set: Who do you want Emma to speak to wh-t?

where wanna-contraction is not possible.[19] This leads them to see that reference points of question words seem to have the same effect as a word in blocking wanna-contraction. They reformulate the hypothesis to cover these data: If there's something between want and to, then you can not contract want and to to wanna. Students then test this hypothesis, working through the data at hand, and searching for counterexamples (there are none). They conclude that the hypothesis covers all of the data, and thus, it seems to be a reasonable explanation for the mystery of wanna-contraction.

At the start of Lesson 7, the class reviews wanna-contraction. Students reflect on how the process of formulating and testing the first hypothesis yielded useful information, despite the fact that it was rejected. By using the methods of science, they came to an explanation of wanna-contraction. They also learned an amazing thing: a reference point--which can not be heard in speech--has the same power as a word in blocking contraction; it is similar to the unseen force of gravity.

Next, the class is introduced to another type of contraction, 's-contraction. Students are asked to use 's-contraction in some sentences; it seems that is can be contracted everywhere. Students are then asked orally to judge the acceptability of 's-contraction for a set of sentences, and to record their judgments on a datasheet. Their judgments show that 's-contraction is not always possible, contrary to their earlier impression. This leads to a problem: When can we contract is? The class discusses what can be done to solve this problem. Students notice that each sentence on the datasheet has a question word, and they recall that question words

[19] If the second hypothesis is not proposed, then the problem can be recast as: When is wanna-contraction not possible? As we learned in our pilot studies (Chomsky et al., 1985), this refocuses students' attention and motivates formulating a hypothesis which explains the constraints on wanna-contraction.

relate to other places in sentences called reference points. Perhaps gathering this kind of data will help solve the problem of 's-contraction. The class reviews how to find the reference points for the question words in these sentences, which are indirect questions. In class or as homework, students are asked to locate the reference points for the question words in the sentences on their datasheet.

Students begin Lesson 8 with a brief review of the problem of 's-contraction, and a discussion of the homework. The class then turns to formulating a hypothesis. Given that this is a contraction problem, it seems reasonable to test the hypothesis for wanna-contraction against the data; unfortunately, it does not explain 's-contraction. Although the wanna-contraction hypothesis does not explain the data, the method used to explain that phenomenon will be helpful here. Before breaking up into pairs or small groups to formulate a hypothesis, students discuss the kinds of patterns they can look for in the data, relating their judgments about 's-contraction to their judgments about the location of the reference points of the question words.

When the class comes back together, two hypotheses are proposed: (1) If the reference point is at the end of the sentence, then you can contract is to 's; and (2) If the is is followed by a reference point, then you can not contract is to 's. After reviewing hypothesis testing, the class turns its attention to the first hypothesis. Since it is clear that the first hypothesis covers the questions on the datasheet, students consider the possibility of counterexamples. By examining the hypothesis, they identify the two forms that counterexamples would take: (a) a question where the reference point of the question word is not at the end of the sentence and is can be contracted, and (b) a question where the reference point of the question

word is at the end of the question and is can not be contracted. Given their experience searching for data of type (a) to test the first wanna-contraction hypothesis, students know that counterexamples of type (a) can be generated by lengthening the sentences in the data set. Thus, the class rejects this first hypothesis and moves on to test the second hypothesis, examining the cases where 's-contraction is not possible. Students work through all of the data before them, and search for counterexamples, finding none. They conclude that this hypothesis is the best explanation for the mystery of 's-contraction. Once again, the ongoing process of formulating and testing a hypothesis has provided useful information which contributed to arriving at the best explanation.

Lesson 9 ends the instructional unit. Students begin by individually reviewing the lessons. On a worksheet, they are asked to first list everything they have learned from the unit, and then to list some evidence that they have rules in their minds about language. Later, as students present what they have learned, the teacher writes their answers on the blackboard or overhead projector, organizing them into three categories: process-related answers (i.e., how problems are solved in science), data-related answers (e.g., voicing, reference points, judgments), and hypothesis-related answers. The class discusses the relationship among the points listed within each category, as well as the relationship among the three categories. Turning to the evidence for mental rules about language, students discuss the various kinds of judgments they made about language phenomena. Knowledge of this sort is a window into the mind: by studying what speakers of a language know, linguists can study how the mind works.

The lesson concludes with a discussion of the essential tool of

science. Although scientists may use special tools in their work (e.g., astronomers may use telescopes; biologists may use microscopes; linguists may use their ears), all scientists share one tool. It is the same tool that the students have used to identify a problem, to choose the kind of data needed to solve a problem, to organize data and look for patterns in data, to formulate a hypothesis, and to search for counterexamples. That tool is the mind. It is the tool that is necessary for doing all scientific work. Unlike many of the special tools used by scientists, the mind is a tool that each person has by virtue of being a human being. And it is the tool that students will take with them into all their science classes. By using the essential tool of science, students have learned much about language and their own minds.

Chapter 3

The Nature of Scientific Inquiry Interview: Talking about Theory Construction

Clearly, students bring to their science courses not only naive theories about the domains of study that conflict with those of the scientist, but also naive theories about the nature of scientific knowledge and how it is gotten--what Posner, Strike, Hewson, and Gertzog (1982) have called "epistemological commitments." A number of science educators and researchers have argued that these epistemological commitments must be challenged and changed if students are to understand the scientist's theories (Gil-Perez & Carrascosa, 1990; Hewson, 1985; Roth, 1984; Smith, 1987). Recent work investigating seventh grade students' understanding of the nature of science (Carey, Evans, Honda, Jay, & Unger, 1989) and their understanding of the nature of scientific models (Grosslight, Unger, Jay, & Smith, 1991) shows that students begin their formal science education in secondary school with a naive realist epistemology of science. On this view, scientific knowledge is seen as a passively acquired, faithful copy of reality; the scientist's hypotheses and models are products of unbiased observation of objects and events in the real world.

Less clear is the extent to which curricular intervention can move students beyond this naive realist position. Carey et al. investigated whether a more mature epistemology could be induced in seventh graders following an instructional experience in theory-building. Using a coding scheme which differentiated three levels of understanding the nature of