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ABSTRACT

Linguistics, as one of the cognitive sciences, has much to offer the teaching of basic science, i.e., the teaching of how to ask and investigate interesting questions. Linguistics is particularly well-suited for teaching about the process of "doing" science because the methodology appropriate to the study of language from a generative viewpoint is, in fact, scientific methodology. Scientific methodology provides an orderly arrangement for, and analysis of, data and a means to search for relationships that explain and predict the behavior of the observed phenomena. The discipline has other practical advantages for teaching the scientific method: it has inherent interest, requires little advanced mathematics because it relies on forms of formal reasoning more easily accessible to many students, requires no expensive laboratories or equipment, has all the relevant data readily available to anyone who has acquired a language, has an immediate connection to computer science, and is central to cognitive science as the study of the human mind. (MSE)

LINGUISTICS IN THE UNDERGRADUATE CURRICULUM

APPENDIX 4-E

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Linguistics and the Teaching of Science

by

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The views expressed are those of the authors and do not necessarily reflect the position of the LSA or the National Endowment for the Humanities.

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PREFACE

The Linguistics in the Undergraduate Curriculum (LUC) project is an effort by the Linguistic Society of America (LSA) to study the state of undergraduate instruction in linguistics in the United States and Canada and to suggest directions for its future development. It was supported by a grant from the National Endowment for the Humanities during the period 1 January 1985-31 December 1987. The project was carried out under the direction of D. Terence Langendoen, Principal Investigator, and Secretary-Treasurer of the LSA. Mary Niebuhr, Executive Assistant at the LSA office in Washington, DC, was responsible for the day-to-day administration of the project with the assistance of Nicole VandenHeuvel and Dana McDaniel.

Project oversight was provided by a Steering Committee that was appointed by the LSA Executive Committee in 1985. Its members were: Judith Aissen (University of California, Santa Cruz), Paul Angelis (Southern Illinois University), Victoria Fromkin (University of California, Los Angeles), Frank Heny, Robert Jeffers (Rutgers University), D. Terence Langendoen (Graduate Center of the City University of New York), Manjari Ohala (San Jose State University), Ellen Prince (University of Pennsylvania), and Arnold Zwicky (The Ohio State University and Stanford University). The Steering Committee, in turn, received help from a Consultant Panel, whose members were: Ed Battistella (University of Alabama, Birmingham), Byron Bender (University of Hawaii, Manoa), Garland Bills (University of New Mexico), Daniel Brink (Arizona State University), Ronald Butters (Duke University), Charles Cairns (Queens College of CUNY), Jean Casagrande (University of Florida), Nancy Dorian (Bryn Mawr College), Sheila Embleton (York University), Francine Frank (State University of New York, Albany), Robert Freidin (Princeton University), Jean Berko-Gleason (Boston University), Wayne Harbert (Cornell University), Alice Harris (Vanderbilt University), Jeffrey Heath, Michael Henderson (University of Kansas), Larry Hutchinson (University of Minnesota, Minneapolis), Ray Jackendoff (Brandeis University), Robert Johnson (Gallaudet College), Braj Kachru (University of Illinois, Urbana), Charles Kreidler (Georgetown University), William Ladusaw (University of California, Santa Cruz), Ilse Lehiste (The Ohio State University), David Lightfoot (University of Maryland), Donna Jo Napoli (Swarthmore College), Ronald Macaulay (Pitzer College), Geoffrey Pullum (University of California, Santa Cruz), Victor Raskin (Purdue University), Sanford Schane (University of California, San Diego), Carlota Smith (University of Texas, Austin), Roger Shuy (Georgetown University), and Jessica Wirth (University of Wisconsin, Milwaukee).

0. Many educators in the United States are currently involved in what Edward B. Fiske in a recent New York Times article calls "Searching for the Key to Science Literacy" (Education Life supplement, January 4, 1987, pp. 20-24). There is a concern that many Americans are ill-equipped by their so-called science education to make rational decisions about the issues in their daily lives that require knowledge about the world of science. Although the United States continues to produce more Nobel Prize laureates than any other country, the average citizen, the average public school student, is rapidly approaching scientific illiteracy. David A. Goslin, executive director for education at the National Academy of Sciences (quoted in the January 4 article) is concerned about democratic society "if a high proportion of its members are uninformed about what constitutes scientific evidence."

The fact is that American students don't study much science, and too often what they do study is badly taught, with emphasis put on what science has, in the past, concluded, rather than on the process of **doing science**. In general, students are not taught to look at the world scientifically; they are not taught to formulate or recognize the interesting questions. As the Times article puts it, "the goal [of science education should be] to convey to students the way in which scientists think and work .... Columbia [University]'s Dean Pollack stresses that science is not a series of conclusions but a way of thinking about the world. 'Science is essentially a structure for asking questions,'...."

The thesis of this paper will be that linguistics, and cognitive science more generally, have much to offer for the teaching of basic science, that is, in the teaching of how to ask and investigate interesting questions. For a number of important reasons, linguistics is particularly well-suited for teaching about the process of doing science. The methodology appropriate to the study of language from a generative viewpoint is essentially that of the natural sciences. Linguistics differs from the traditionally recognized natural sciences, however, in that it is a branch of cognitive science. For the reasons to be discussed below, this makes it particulary advantageous for science teaching. This paper will first illustrate that linguistic methodology is, in fact, scientific methodology. It will then proceed to outline the particular advantages linguistics provides in science education.

1. In the science classroom, students are still taught (at the most naive level) that to do science one must:

a. carefully observe some aspect of the world;
b. collect and organize the observations;
c. search for regularities within the observations;

d. draw logical conclusions based on the observations;
e. test the conclusions (in a laboratory-type environment).

While there might be much discussion about the value of these steps in the day to day work of science, to the extent that they actually have anything to do with "the scientific method" and "doing science", linguistics is an appropriate teaching tool. (Criteria of this sort are often introduced in the early chapters of textbooks for laboratory science, see for example Cotton and Lynch, Chemistry: An Investigative Approach.) The observations relevant to points a.-d. will be of linguistic phenomena. The tests of point e. are readily conducted in terms of native speaker intuitions about the grammaticality of sentences. This can be illustrated by a sample linguistics "lesson".

Let us take an example of controlled and organized observation about which conclusions can be drawn and tested. The students' attention can be directed toward certain sentences of English that happen to contain the words up and down in a particular grammatical construction. (Following general convention in linguistics, an asterisk preceding a string of words indicates that the string is not a good sentence of the language under investigation, that is, the string is ungrammatical.)

The linguistic observations:

(1) John looked the information up.
John wrote the telephone numbers down.
John looked it up.
John wrote them down.
John looked up the information.
John wrote down the telephone number.
*John looked up it.
*John wrote down them.

These observations can be organized according to whether the direct object in the sentence is a full noun phrase (e.g. the information) or whether it is a pronoun (e.g. it).

Organization.:

(2) Noun phrase direct objects

look the information up
write the numbers down
look up the information
write down the numbers

(3) Pronoun direct objects

look it up
write them down
*look up it
*write down them

Once the data is appropriately organized, certain regularities emerge with respect to the distribution of direct objects and the words up and down.

Regularities:

Noun phrase direct objects can be preceded or followed by up and down. Pronoun direct objects can be followed by up and down, but they may not be preceded by them.

Several logical conclusions can be drawn, based on the observable regularities.

Conclusions consistent with the data:

a. Sentences cannot end with pronouns.
b. Pronouns must immediately follow verbs.
c. Two-part verbs like look up and write down can be followed by noun phrases but not by pronouns.

Each of the logical conclusions can be tested. The tests are laboratory-type experiments in that they are invented by the scientist and performed in an artificial and controlled environment.

Testing of the possible conclusions:

a') Can a sentence end with a pronoun? The test involves constructing a sentence with a pronoun at the end: John talked to him. The fact that this sentence is grammatical disconfirms conclusion a), causing it to be rejected.

b') Must a pronoun always immediately follow a verb? The test involves constructing sentences in which a pronoun does not immediately follow a verb: He talked to John, John talked quietly to him. These sentences are grammatical and therefore conclusion b) is disconfirmed and rejected.

c') Is it true that look up and write down can be followed by noun phrases but not by pronouns? Evidence is found by making up further English sentences:

(4) Mary tried to look up those old quotations.
Susan looked up her old friend.
*She tried to look up those.

*She looked up her.
Jill wanted to write down the appropriate answer.
*Jill wanted to write down it.

Each of these sentences supports conclusion c). In fact, no sentence of English will be found to disconfirm it. Furthermore, the conclusion seems to be accurate not only about the two two-part verbs in the given data, but also about other such verbs:

(5) John picked up the baby.
John picked the baby up.
John picked it up.
*John picked up it.
John threw the newspapers out.
John threw out the newspapers.
John threw them out.
*John threw out them.

Conclusion c) is supported by the test and is consistent with all the collected observations.

Of course, as any generative linguist or other practicing scientist would comment, there is much more to science than the orderly arrangement and analysis of some collected data. At a more sophisticated level, science is understood to be the search for relationships that explain and predict the behavior of the observed phenomena. On this view, to do science a student must learn and appreciate the meaning and value of scientific theories.

A student educated in the "culture of science" must recognize (at least) the following points (summarized, in large part, from Williams, Trinklein, and Metcalfe (1980) Modern Physics; Chomsky, particularly (1957) Syntactic Structures; and Newmeyer, (1986) "Has there been a 'Chomskyan revolution' in linguistics?", Language 62, 1-18):

a. that science deals in **principles** that describe natural phenomena;
b. that science involves **theory formation**;
c. that a scientific theory must **explain** observed phenomena;
d. that science involves **model** building;
e. that scientific theories are judged useful with respect to whether or not they **predict** previously unobserved behavior;
f. that scientific theories are subject to **experimental testing**;
g. that science necessarily involves **hypothesis formation**;
h. that hypothesis formation requires **imagination** and that discovery procedures play a very limited role;
i. that there is an important distinction between discovery

procedure and evaluation procedure, or **practical description** and **formal theory**;

j. that scientific conclusions have a special responsibility to **truth** about the observable world;

k. that a crucial experiment can disconfirm, but that no amount of experimentation can show an hypothesis to be necessarily true, and therefore, that scientific **open-mindedness** is important.

These points of scientific methodology are central to research in generative linguistics. This is persuasively argued by Chomsky in the chapter "Goals of linguistic theory" of his book Syntactic Structures. There the case is made for approaching **grammar** as a theory of language. Grammar construction is seen as model building and the grammar is expected to make accurate predictions about native speakers' knowledge of language. Chomsky argues that grammars, just like theories in the physical sciences, are subject to constraints on construction and evaluation. Criteria for choosing the best grammar are essentially the same as the criteria for choosing the best theory in any other scientific endeavor. The grammar, the theory, must be subject to experimental testing, and it must meet criteria of both internal and external adequacy. The grammar must be internally consistent (free from self-contradiction) and must be consistent with other good theories of allied phenomena (for example theories of other human cognitive capacities). A scientifically interesting grammar is evaluated in terms of its usefulness in explanation, or in other words, its relationship to truth. A grammar is successful only to the extent that it does in fact explain speakers' knowledge of grammatical sentences.

These last points can be exemplified by the following sample "lesson" of a grammatical rule as a theoretical construct that explains a certain phenomenon and predicts certain new observable facts:

Observation: Sometimes two different sentences can mean the same thing. For example:

(6) a. Susan gave the book to Jill.
    b. Susan gave Jill the book.

How can it be that speakers of English know that these two sentences mean the same thing even though they are different in form?

Hypothesis: A grammatical principle, a meaning-preserving rule of grammar, relates sentences of type (6a) to sentences of type (6b). This hypothetical rule involves only sentences with verbs that take two objects, that is, ditransitive verbs. Informally stated this rules says:

Ditransitive verb phrases can be made up of a Verb followed by a Direct Object Noun Phrase followed by an Indirect Object Prepositional Phrase; alternatively, a ditransitive verb phrase can be transformed into a Verb followed by an Indirect Object Noun Phrase followed by a Direct Object Noun Phrase.

This rule of grammar is a principle that accurately describes the relationship between sentence (6a) and sentence (6b). It is also a theory in that it explains (or purports to explain) the relationship between these two sentences: native speakers of English recognize sentences (6a) and (6b) as related because the hypothesized rule is part of their grammar. This explanation takes (6a) and (6b) not as an isolated fact, but as evidence of a general principle.

The hypothesized rule involves model building in the sense that it utilizes theoretical constructs, like "ditransitive", "phrase", "object", etc.

The rule predicts the occurrence of new data, for example:

(7) Joe mailed the letter to Bill.
Joe mailed Bill the letter.
Daddy baked cookies for the children.
Daddy baked the children cookies.
Etc.

The rule is subject to testing. If correct as stated, then every ditransitive verb will be found in both of the indicated sentence variants.

The rule is an hypothesis and was discovered by the use of imagination, that is, there is no discovery procedure that would necessarily lead to this particular rule.

This rule will be evaluated as "right" or "true" just to the extent that its empirical predictions are accurate, that is, to the extent that all ditransitive verbs can in fact occur both ways.

The rule as stated can be disconfirmed by evidence like the following:

(8) We contributed $10.00 to the zoo.
*We contributed the zoo $10.00.
We fabricated an alibi for the judges.
*We fabricated the judges an alibi.

The data in (8) provide empirical evidence that the hypothesis, the proposed rule, is in need of modification. If it cannot be modified appropriately, it will need to be replaced by a more adequate rule.

Ultimately the theory, the grammar, will be a set of all the "true" rules for the language under investigation.

2. Once it is understood that generative linguistics is a scientific discipline, the argument can be made that it can be used particularly advantageously in the teaching of science. The argument proceeds in two stages: first, that cognitive science provides important opportunities for science teaching, and second, that linguistics is the most appropriate subfield of cognitive science for such a program.

Cognitive science is the study of innate or acquired knowledge and of the beings, particularly humans, who have this knowledge. The disciplines that together have come to be known as cognitive science include linguistics as well as certain aspects of psychology, artificial intelligence, neuroscience, anthropology, and philosophy. As Gardner, (1985) The Mind's New Science, puts it, cognitive science is the "empirically based effort to answer ... epistemological questions."

As can be argued based on the large numbers of students in psychology classes (most of which are definitely not taught as science), students are naturally interested in things having to do with "human nature." It would seem obvious, from enrollment data, that most students are more interested in the nature of memory, language, vision, etc., than in the nature of mass, energy, valences, and hydrocarbons. The epistemological underpinnings of cognitive science make it especially appealing to large numbers of students. A university intent on improving the basic level of understanding of scientific inquiry should capitalize on this evident interest on the part of students. The prediction is that a course designed to teach scientific methodology, to instruct undergraduates in the "culture of science," will be more successful if the methodology is taught based on subject matter that the students find inherently interesting. Ideally then, this inherent interest will be stimulated and scientific inquiry will be extended to other areas, including the traditional natural sciences.

As the above-mentioned Times article makes clear, science literacy is not a problem for the bright and highly motivated students who are naturally attracted to math and science. The issue of problematic science teaching is relevant to the typical liberal arts student who does not plan to continue on in the study of science, and who may not understand the central importance of science to liberal arts. Such a student may not even realize that science is a part of a liberal arts education. This connection is easily seen through the study of cognitive science because of its epistemological nature. Its relationship to philosophy and the humanities more generally is easily understood because the topics of discussion are so often similar. (This general point is also made, in rather different terms, in Heny, (1987 manuscript) Linguistics in a Liberal Education.)

Another advantage of cognitive science for science teaching is that little advanced math is necessary (this point is from Heny, op.cit.). While the importance of the teaching of mathematics in and of itself should not be underestimated, formal reasoning can be taught without it. Entrance into courses in the various areas of cognitive science, such as linguistics, need not depend on requirements in the advanced math that many students do not (cannot?) master, e.g. the plane geometry, trigonometry, and calculus necessary for physics. Cognitive science depends more crucially on the type of formal reasoning encountered in early courses in symbolic logic or first order predicate calculus. These will in general be more accessible to the typical undergraduate than more advanced mathematics.

Once it is demonstrated that cognitive science has advantages for the teaching of science, the further argument can be made that within cognitive science, linguistics is particularly relevant for teaching purposes.

As a practical matter, linguistics is "cheap." It requires no expensive laboratories or equipment. Additionally, all the relevant data is readily available to everybody who has acquired a language. Students become involved in the scientific investigation of their own language, and every student has equal access to both the data to be studied and the necessary "equipment" for studying it. Because no high-cost laboratory installation is necessary, and because any human language is equally valuable as the domain of investigation, there is no inherent inequality among schools subject to different funding bases. Linguistics can be taught equally well in poor schools and in well-funded schools. (This point is argued convincingly by both Ken Hale and Wayne O'Neil, personal communication.)

Another relevant practical matter involves the fact that linguistics has an immediate connection to computer science. Regardless of what effects computer science is having on linguistics proper (there are those who would argue that the main effect is to drive linguistics away from its basic aim of studying human cognition), the relevance of linguistics to computer science is undeniable. Advances in computation are becoming increasingly dependent on the kind of input about language that linguists are uniquely capable of supplying. This means that students will see the career opportunities available through the study of linguistics. Regardless of the long-term effect that this will have on the state of scientific linguistic inquiry, it is something that educators can exploit in attracting students to a field where they will learn scientific methodology.

Finally, to the extent that cognitive science is the study of **human** cognition, the human mind, linguistics is central to it. Aspects of language structure are determined by the structure of the mind and, importantly, language is peculiar to humans. The study of human cognition cannot proceed in a meaningful manner without attention to language. Linguistics could well serve as the core of a curriculum in cognitive science.

Returning briefly to the Times article with which this essay began, James Rutherford of the American Association for the Advancement of Science is quoted as saying, "Science is not a list of facts and principles to learn by rote; it is a way of looking at the world and asking questions ... Kids go in, set up some equipment, gather data and verify a predetermined conclusion --all in 45 minutes. And verifying what Newton did 300 years ago is hardly science. Does anyone ever ask whether Newton might have got it wrong?" An important advantage of linguistics is that it is a very new science. It is so new that even relatively young researchers can be creatively involved in issues at the forefront of the discipline, often showing that some other researcher in the forefront in fact "got it wrong."

A fitting summary to any paper on the value of linguistics in science teaching comes from Hale's (1975) MIT manuscript Navajo Linguistics: Part I:

> One might well ask why it is useful to study a language which one already knows. The answer to this question is a rather long story, but it is the same as the answer to the question "why do we study biology, chemistry, and physics?" "Why do we study science at all?" The reason is that we wish to find explanations for the things that we observe....
>
> The study of language -- i.e. linguistics -- is also a science. We know that people are able to speak languages, but we know very little about what this means....The question is: why [are they] able to do this? The linguist tries to answer this question. He tries to construct a theory which will account for this ability....
>
> Linguistics is not a physical or biological science; rather, it is the study of a certain aspect of the human mind. We know that a person's knowledge of his language is stored in the brain, but we cannot observe it directly. What we do observe is his speech -- on the basis of this, we try to construct a theory of what is in the brain. This is exactly what is done in other sciences -- if some object is not directly observable, a theory, or model, is constructed which can duplicate the observable behavior of the object.

The theory is correct to the extent that it can accurately duplicate this observable behavior.

The linguist 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 a knowledge of his own language; he can therefore observe his own speech.

What defines a science is not the phenomena that it purports to explain (i.e. aspects of the physical world), but rather the manner of inquiry, the methodology, that is used in attempting to achieve that explanation. In this sense cognitive science in general, and generative linguistics in particular, qualifies, along with physics and biology, as science. In the curriculum planning which will be inevitable to improve the teaching of science on the nation's college campuses (as well as in the high schools and grade schools), the advantages of linguistics should not be overlooked.