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As if to underscore the educational significance of children's verbal "scientific" (scientific at least by intention, if not in fact) explanations, Lemke (1990, p. 100) asserts: The job of science education is, at the very teach students how to use language....this means, at least, teaching them to "talk science" in class, on tests, in talking their way through to the solution of a problem (aloud or to themselves), and in writing or **speaking** [emphasis added] about issues to which science is relevant. Therefore, the more we know about the verbal scientific explanations students are currently able to construct (prior-knowledge-in-action), the better we can modify science curricula and target science instruction.

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The Lexical Analysis of Students' "Scientific" Explanations: Implications for Learning Theory

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Words are the wagons we use to carry our concepts. If, as Novak (1977, p. 18) argues, "Concepts are what we think with," then the words (concept labels) science students use betoken the degree of conceptual sophistication of their cognitive structures. Researchers in the alternative conceptions movement (ACM) have long recognized the importance of the words that science students choose to use in their spontaneous verbal explanations of natural phenomena, considering the propositions in which these words are embedded to be indicative of students' understanding of science concepts and principles. In fact, the clinical interview is the research method of choice within the ACM principally because it is an effective generator of children's verbal knowledge claims about natural objects or events, and thus can reveal how children think the world works (Novak & Gowin, 1984).

As if to underscore the educational significance of children's verbal "scientific" (scientific at least by intention, if not in fact) explanations, Lemke (1990, p. 100) asserts: The job of science education is, at the very teach students how to use language....this means, at least, teaching them to "talk science" in class, on tests, in talking their way through to the solution of a problem (aloud or to themselves), and in writing or **speaking** [emphasis added] about issues to which science is relevant. Therefore, the more we know about the verbal scientific explanations students are currently able to construct (prior-knowledge-in-action), the better we can modify science curricula and target science instruction.

Just what do we know about the use of verbal scientific explanations in the science classroom? Dagher and Cossman (1992) studied the verbal explanations employed by junior high school science teachers during science instruction by analyzing classroom discourse. The researchers identified 10 types of verbal explanations given by the teachers. Of the 10, 4 were much more common than the rest. Those explanations, in order by descending frequency, were: (a) genetic explanations (those supplying an antecedent sequence of events); (b) mechanical explanations (those which are machine-like, physical-causal); (c) practical explanations (those that tell how to do something); and (d) analogical explanations (those that compare a familiar situation--the analog--to the unfamiliar scientific phenomenon --the target--and point out parallels). From their classroom discourse study, it appears that mechanical and practical explanations are favored by teachers of the physical sciences, whereas teachers of the life sciences prefer genetic and analogical explanations. On average, the 20 science teachers who took part in the study used 5 different types of explanation per science class period. If, as Lemke (1990, p. 170) implies, students tend to emulate the types of scientific explanations given by their teachers during classroom instruction, then student explanations may reflect not only their own scientific understanding, but also that of their science teacher.

Central to the transcript categorization process employed by Dagher and Cossman (1992) were (a) the words embedded in the science teacher's propositions and (b) the context in which each verbal explanation was deployed. In contrast, many of the published ACM studies focus on science students' inability to construct currently valid scientific propositions, while ignoring the **characteristics** of the scientific explanations those students do offer.

The preceding statement is not meant to imply that just because a student lacks the accepted word label, that student cannot have grasped a particular science concept, but personal and culture-based lexical gaps can hinder the assimilation of new concepts--especially if they are to be learned via reception learning. A number of studies have shown: (a) that people learn and recall things more easily if the new concepts involved correspond to words they already understand and (b) that when a language lacks a word label for a particular concept, people in that culture have a more difficult time making that conceptual distinction (Crystal, 1987, p. 15). A modified version of the Sapir-Whorf hypothesis is generally accepted in psycholinguistics today, namely, that while it may not determine the way people think, their native language does affect their facilty to perform mental tasks and also the way they perceive and remember things (Crystal, 1987, p. 15).

It should also be pointed out that the verbal explanations science students generate appear to be an indicator of their understanding of the nature of science (Lemke, 1990, pp. 124-126). Thus, such explanations lie at the boundary between cognition and epistemology, just as words lie at the boundary between syntax (the study of word arrangement to show relationships) and morphology (the study of the internal meaning structure of words).

Hayes (1992a), in a sense, examined the scientific explanations of **scientists** when he investigated word usage within the basic science research articles contained in the world's 10 leading science journals. He found that those articles became progressively harder to read in each of the last four decades of this century. For example, during their first 77 years of publication, both <u>Science</u> and <u>Nature</u> were written at the level of the typical leading newspapers of the day and required no special scientific background to understand. Today, both challenge the comprehension abilities of even scientists when they try to read an article outside of their discipline, since, as Hayes discovered, they have become publication venues "for specialists" who can communicate succinctly with arcane polysyllabic vocables and high density graphic representations of their data sets. At at a time when science educators are aiming at scientific literacy for all citizens, the explanations given by scientists themselves are becoming "incomprehensible to all but a few initiates (Hayes, 1992a, p. 739). His research centered on the lexical (vocabulary) difficulties inherent in scientific text (the printed discourse of the scientific community) and it found few signs that that the current trend toward greater complexity is reversing.

As Lemke (1990, p. 99) points out, we make via language--supplemented by diagrams, mathematical equations, and hands-on experiences:

> In terms of language, we do know what a scientific theory or conceptual system must be: it is a thematic pattern of semantic relationships in a subject, one that is reconstructed again and again in nearly the same ways by members of a community."

Since semantics is the study of meaning in language, semanticists prefer to speak of lexemes (units of meaning that differ somewhat from concepts) instead of words. In semantics, <u>run,</u> <u>runs,</u> <u>running</u> and <u>ran</u> are not different words but variants of the same underlying unit of meaning--a unit called the <u>lexeme</u> (Crystal, 1987, 104).

All of the lexemes (e.g., red, green, blue) related to a more general lexeme (e.g., color) constitute what is called a semantic field. In translation to Ausubelian learning theory (Novak, 1977), one could estimate the degree of progressive differentiation for the general concept of <u>color</u> by probing a student's semantic field of <u>color</u>. Interestingly, Berlin and Kay studied the color systems of 98 languages and found there seems to be a universal inventory of 11 basic color categories and all languages use only those 11 or fewer categories (Crystal, 1987, 106).

Lexical analysis is the statistical analysis of patterns of word choice in texts (Hayes, 1992b). If it is true that investigation of sentence meaning (the meaning of propositions, units of meaning that describe some state of affairs) is probably the most important trend in modern semantics (Crystal, 1987, p. 107), then lexical analysis may offer another index of conceptual development for ACM researchers and provide a more objective (albeit inferential) way of documenting conceptual change.

PURPOSE, QUESTION, HYPOTHESES, AND METHODS

The purpose of this study was to examine a subset of clinical interview transcripts, drawn from a typical cross-age alternative conceptions study in science education, in search word choice patterns.

It was hypothesized that: (a) the particular words students use to convey their current understandings of science topics constitute an apt indicator of their degree of conceptual development in that domain; (b) descriptive statistical measures of students' word choice patterns will approximately parallel and enrich the analysis of traditional qualitative findings; and (c) computer-based lexical analysis can serve as a valuable new tool for science education research.

The present investigation was designed to use actual research transcripts from a recent cross-age ACM study and to focus on a single science topic, namely insect metamorphosis. Since that study (Nichols & Wandersee, 1993) used multiple methods of data collection and analysis, the results of the current lexical analysis can be compared and contrasted with the findings generated by more conventional approaches. The cross-age characteristic of the study from which the transcripts were drawn for lexical analysis means it was designed to describe conceptual change across grade levels via a single data slice in time. Therefore the resulting lexical analysis may be able to speak to conceptual change across

The theoretical implications of this study for elaboration of learning theory are as follows. If, as Novak and Gowin (1984) contend, propositions are like molecules of meaning, and if these are constructed primarily with concepts having word labels, then the more science education researchers learn about not only the concept linkages but also the verbalized concept selection patterns of science students as they construct "scientific" explanations, the better the researchers will be able to elaborate learning theory to accommodate the actual restructuring that occurs during conceptual change. In so doing, the theory will better be able to describe, explain, and predict the moves on science learning.

<u>Subjects</u>

The 12 subjects whose scientific explanations are described in this study were chosen randomly by category from the 24 participants in a recent cross-age study (Nichols & Wandersee, 1993) of public school students' alternative conceptions about insect metamorphosis. In that study, the students were chosen by purposive sampling from several schools in a large city located in the Deep South. They represented grades 5, 7, 9, and 11. Students were selected to include categories of low, medium, and high science ability, as inferred from previous science course grades, science teacher interviews, and science scores on a national, norm-referenced achievement test. The 12 in-depth clinical interviews on which this study's transcripts were based employed interview probes that used live insects (crickets, and mealworms in various stages of metamorphosis) which students had not seen in school.

Procedure

The 12 typed transcripts were converted to ASCII text files and computer analyzed using QLEX lexical analysis software (Hayes, 1992). The QLEX suite of programs constitutes an original laboratory research tool, not a commercial applications package, and thus has adequate but not user-friendly documentation. The software runs on IBM-PC compatible machines (386 or 486) that have extra memory and a mathematics (installed. It is not written for the MS-WINDOWS graphical user interface. Texts to be analyzed must be edited following explicit rules after being converted to an ASCII file--to insure comparability with the Cornell corpus. The author expresses his thanks to Donald P. Hayes, Cornell Department of Sociology, for granting permission to use QLEX in his research program.

QLEX software compares the lexical (vocabulary) difficulty of the researcher's text or speech transcripts with the average lexical difficulty of 60 international newspapers published in English. That average is represented by O on the QLEX scale, and the scale ranges from -120 to +85.8, plus being greater lexical difficulty and minus being less than the referent newspapers. Since one of the main determinants of text complexity is its patter.. QLEX is standardized around newspapers. It is known that British and American newspapers have exhibited a log normal word selection patterns since at least 1730.

The QLEX software compares multistage stratified random samples of the researcher's text with the linear cumulative frequency distribution pattern of newspapers. QLEX compares the 10,000 most common English words with the words in the researcher's text and then and generates a cumulative curve from the words in that text--beginning with the proportion of the most common word the, to which is added the proportion of the next most common word of, all the way down to the 10,000th word (estimates of word frequency considered reliable are not available for words beyond 10,000). Next, the 75 most common English words (about half the words in most texts) are deleted, since they contain little information and it is important to focus on content words. Finally the researcher's text curve is compared with the composite newspaper text curve. Thereby a LEXl statistic for the text is computed.

It is known that spontaneous speech underuses the more common grammatical words, overuses common substantive words, and underuses the rarer substantive words. However, science talk is more sophisticated than common spontaneous speech.

It is also known from reading research that knowing the meanings and uses of uncommon words is a strong predictor of reading comprehension (Saarnio, 1990). In addition, the QLEX scale has been calibrated by comparative measurements across its full range for both print and natural language sources and has been based on an explicit lexical model and on a theory in social psychology. The Cornell Corpus is a 3+ million-word corpus with over 4,000 sample texts selected to cover the full range of texts (print, TV/radio, conversation) and thus provide the QLEX scale for evaluating the LEX statistic--one of the single best measures of text difficulty and an indicator of the requisite sophistication of the audience. Table 1 shows some of the calibration points on the QLEX scale so the read__ iarize him-/herself with it in preparation for evaluating the LEX1 statistics cited in the current study.

Table 1
Hayes' Computed LEX Statistic Values for Science Text and Speech Sources Relevant to This Study

Source--(Hayes, 1992b, p. 4)	LEXl statistic
Science (1990)	48.0
Scientific American (1991)	14.3
Time (1984)	6.4
NEWSPAPERS, World, English (60)	0.0
People (1985)	-6.4
Ranger Rick	-18.4
Winnie the Pooh (storybook)	-43.3

RESULTS

The following results results apply to the 12 insect metamorphosis transcripts being analyzed--namely, those from low, medium, high ability American public high school students in grades 5, 7, 9, and 11.

The LEXl statistic values for the 12 transcripts that were computer-analyzed ranged from -12.80 to +16.73, with an overall mean of +0.91. This means that the average verbal explanation offered by students in this study had a lexical difficulty rating approximately equivalent to that of the major English newspapers (0.0). The fact that the science conversations tended to involve more residuals (words that are not in QLEX's 10,000-word dictionary of the most common English word-types) than a newspaper is important to note. Newspapers tend to have about 10% residuals in a given word-sample. The transcripts analyzed here exceeded that rate in all but one case.

In contrast, the interviewer's LEXl statistic was 9.32 (for one of the 12 transcripts chosen at random, since she used a common battery of probes). This means she was asking questions at a students' responses--as one might expect. Her verbal probes were thus about the level of difficulty of Time magazine, according to Hayes' LEXl scale. Closer analysis revealed that the mismatch in level of difficulty was due primarily to three evolution-based probes centered on natural and artificial selection, in which words like population, generation, insecticide, predator, industrial pollution, and so forth were used. Another computer program, RIGHTwriter for Windows (Que Software, 1991), placed the readability level of her entire set of interview questions at the 7th-grade level, which seemed reasonable.

Most students tended to use only a few types of explanations. The most common were the genetic (historical or sequenced) and rational (evidence-based) explanations. This coincides with the life science teachers' preferences for genetic and analogical explanations, as was hypothesized. In addition, functional and mechanical explanations were also to be found in many transcripts. Most disturbing were the occasional occurrences of teleological and anthropomorphic explanations in which conscious striving toward goals and human-like behavior were ascribed to insects. The Dagher and Cossman (1992) typology of explanations seemed to fit the student responses remarkably well, even though the system was originally devised for teacher explanations, not student explanations

Table 2 shows the Dagher and Cossman (1992) typology of verbal explanations.

Table 2 Types of Verbal Explanations Given by Science Teachers (Dagher & Cossman, 1992, p. 369)

Types and subtypes	Desirability in science class	
tautological		(-)
metaphysical		(-)
anthropomorphic	(-)	
teleological		(?)
analogical	(+)	
mechanical	(+)	
functional	(+)	
genetic *	(+)	
rational *	(+)	
practical		(+)

Note. * = most common explanations offered by subjects in this study.

It is interesting to compare the concept maps of the interview transcripts to the LEXl statistics and to the Flesch-Kincaid readability index. Hayes (1992b) notes that correlations between Flesch readability scores and LEXl are on the order of .6, even though the readability ratings are more syntactic than lexical. The RIGHTwriter for Windows software was used to analyze each transcript using the Flesch-Kincaid formula for readability. This is the standard used by the US government for manuals and documents. RIGHTwriter shows an average error rate for its readability calculations as a respectable 2%--which is lower than the error rate for human operators (Que Software, 1991). It also uses the entire text for data, eliminating sampling error. The Flesch-Kincaid readability index is based on the variables of mean syllables per word and mean sentence length, both with weightings. Its index numbers correspond to the school grade level needed to understand the wording of the sample, making interpretation easy. Table 3 compares concept map scores, LEXl statistics, and reability index values _ the 12 transcripts. Note the greater concordance for the readability index.

Table 3
Lexical Sophistication of Students' Verbal "Scientific" Explanations (via LEXl and ReadabilitY Index Values) versus Concept MaP Scores Based on Level of Understanding

	Science ability level								
	Low			Medium			High		
Grade	Map	LEXl	RI	Map	LEXl	RI	Map	LEXl	RI
	2nd	2nd	2nd	2nd	1st	3rd	1st	3rd	1st
	2nd	3rd	2nd	2nd	1st	3rd	1st	2nd	1st
	1st	1st	3rd	3rd	2nd	2nd	2nd	3rd	1st
	3rd	1st	2nd	1st	3rd	1st	2nd	2nd	3rd

Note. For comparison purposes, scores and values were converted to ranks, from most sophisticated to least within each grade level. Concept maps were scored by rating each transcript map proposition as no, limited, partial, or complete understanding and totaling the scores numerically.

The QLEX program offers a table of residual words not found in its standard lO,OOO-word dictionary. This was helpful in comparing two transcripts with identical mapping scores to weigh which was more sophisticated or precise. The listing calls rare or extremely scientific words to the researcher's attention when they might be overlooked while embedded in a map or transcript. Many word processors have a frequency count feature that will list words in a text in order by frequency.

DISCUSSION AND SUMMARY

This was an exploratory study which sought to investigate the value of computer-based lexical analysis for evaluating students' "scientific" explanations in alternative conceptions studies.

The author is aware of the fact that students are known to sometimes use sophisticated terms without understanding them. Thus, a lexical analysis, by itself, could delude the researcher into thinking that the student whose transcript is being analyzed has learned more than he/she really has.

On the other hand, coupled with other evaluation tools, lexical analysis can help tease apart differences in levels of understanding that other methods might miss--since mastery of word labels is the initial mark of understanding. One can also identify an advanced verbal explanation quite easily by noting the residuals in the transcript with a highlighter pen and reading those sentences. The facts are that: (a) LEXl statistics can be compared across studies, (b) the computer-based analysis eliminates much of the bias and error inherent in hand-scoring systems, (c) the fixed zero point on the QLEX scale allows worldwide comparison of English-language transcripts, (d) the 10,000-word standard dictionary gives a fixed point of reference, and (e) as "talking science" is emphasized more and more, we need ways of comparing the progress of our science students that include the scientific lexicon.

In addition, quite by surprise, the author noted that even the simpler computer-based readability index can help evaluate the lexical/syntactical complexity of students' "scientific" explanations. This tool is more accessible to researchers at present.

The lexical analysis (QLEX) software is somewhat difficult to install, run, and understand. You must be DOS-literate. It can take a week or two to get "up and running." Safeguards must be taken by the researcher to make sure that a run yields reasonable results; this author suggests using your own created file of the IRS Form 1040 text and comparing it to Hayes' results as a benchmark test. There are quirks in the program that make running it a full~concentration activity. Yet, the exploration may prove well worth your efforts. The particular words students choose for their "scientific" explanations reflect their current understandings--albeit indirectly. LEXl and Flesch-Kincaid readability index values were found to somewhat parallel scores of propositional understanding, plus provide new information. Since the sample size was moderately small and this study was intended to be exploratory, inferential statistics were not employed. However, from this initial traverse of the territory, it is not unlikely that computer-bas serve as a valuable new tool for science education research on alternative conceptions. Why not investigate the possibilities yourself.

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