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Integrating science concepts into intermediate English as a second language (ESL) instruction[1]

Rochel Gelman, George Meck, Laura Romo, Betty Meck, Wendy Francis & Catherine O. Fritz
Psychology
University of California, Los Angeles

Abstract

Findings on the nature of conceptual learning encouraged us to develop a way to offer instruction about science to English as a second language (ESL) students. We review one way to do this, which is to embed opportunities to learn about science and its related tools within the reading and grammar lessons of ESL instruction. In-

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Address inquiries related to the manuscript to Rochel Gelman, Dept. of Psychology, UCLA, Los Angeles, CA 90024-1563 or to rochel@psych.ucla.edu. Inquiries about the curriculum should be directed to George Meck at Birmingham High School, 1700 Hayes St., Van Nuys, CA 91406.

termediate level high school ESL students were offered reading materials designed to feature relationships between concepts in the biological and physical sciences. These were paired with opportunities to do experiments in teams, keep records and give reports. Evidence that students were able to attend to, and start to learn about both the language and content of science is presented within the context of a broader discussion on the need to develop evaluations that index on-line learning in a way that can be used by teachers.

Introduction

Findings from cognitive science, cognitive development and educational psychology converge on common themes about the nature and acquisition of mathematical and scientific knowledge. First, most students come to their science classes with naive, informal theories of biology, mechanics, heat, energy, motion, the earth, electricity and so on; theories that are either inconsistent or incompatible with current scientific understanding of these domains (cf. Carey 1985, 1988; Deadman & Kelly 1978; Larkin 1985; Larkin, McDermott, Simon & Simon 1980; Vosniadou & Brewer 1992). For example, many college students' beliefs about the way that inanimate objects move are closely related to Aristotelean or Medieval notions of energy, notions that no longer play a role in scientific thought and research (Chi 1985; Chi, Glaser & Rees 1982; McCloskey 1983; Mestre 1991).

Second, learners are actively involved in their own knowledge acquisition. No matter what the domain, they interpret novel data on the basis of the organized knowledge structures they already have (Gelman 1994; Glaser 1988). When the structure of novel input from students' lessons is inconsistent with the principles and related core concepts of their existing knowledge structures, the chances are high that they will ignore or misinterpret their lessons. These are reasons that acquisition of a new level of principled understanding of science and mathematics is hard. Another problem arises from the fact that the meaning of language of science and mathematics is intricately related to the core concepts and principles within these domains. For example, "multiply" has a different meaning in a natural language than it has in the language of rational numbers when fractions are combined in an equation that represents the operations of multiplication (Gelman 1994). Similarly, "addition" does not mean the same thing when used in a sentence about adding hydrogen and oxygen as it does in one about adding positive integers.

A change in conceptual understanding cannot occur overnight. Learners and instructors have to make a concerted, in-depth commitment if students are to achieve an understanding of concepts that differ from the intuitive ones students bring to the classroom (Carey 1986, 1988). Many researchers and educators have noted that these results point to the need to teach more science and mathematics—even in the elementary grades. This requires that students spend more, not less, time on task. However, it will not be sufficient to simply add opportunities to learn scientific vocabulary or to offer remedial or survey courses in science (cf. Beck & McKeown 1989). Instead, ways have to be found to present many examples of core concepts—methods that help organize the structure of a domain—and to give students the chance to "do science," to use and communicate with the language and tools of the scientific domain. Given that these are problems that all students face in becoming scientifically and technically literate (Moore 1989), let us consider why ESL students might be at special risk in this regard.

Our goal has been to develop ways to make science learning an ongoing part of the regular ESL classroom. It has been common practice for school systems in the United States to wait to enroll limited English proficient (LEP) students in science classes until they have achieved target levels of English proficiency in an ESL program. For example, although the June 1994 Los Angeles Unified School District (LAUSD) Master Plan for LEP students calls for students who already have passed the Level 2 ESL program to enroll in science classes that are given in English, these were still separate classes for ESL students.

The assumption that English proficiency is a necessary prerequisite for enrollment in regular high school science courses is not without justification. Typically, these classes are conducted in English and the texts are written in English. However, if LEP students are delayed in their introduction to regular science classes, they will have even less opportunity than their English-speaking cohorts to take the very science courses that will enable them to advance beyond their naive, and often wrong, theories about scientific matters. This also means that LEP students are less likely to take enough of the science and technical requirements for many of the career paths they might want to follow.

Others in the field of ESL acquisition address this problem by encouraging educators to provide relevant informational content and opportunities for contextualized, rather than fragmented, language use in the classroom (Binton, Snow & Wesche 1989; Kessler & Quinn 1987). Here we present a report of one way to embed the lessons of the cognitive and learning sciences into an ongoing ESL curriculum at Birmingham High School, an LAUSD high school in the San Fernando Valley in Los Angeles. The program is guided by the kinds of principles that cognitive scientists recommend when one adopts the classroom as their learning lab (cf. Breuer 1993, for a review). Specifically, these mean that the science content in ESL instruction should: (1) be selected and presented in ways that take into account the students' informal theories regarding natural phenomena; (2) build inter-related knowledge bases; (3) help students re-organize their knowledge as they acquire new knowledge bases; (4) include ways to encourage students to think scientifically, for example, to solve problems and generate hypotheses that they can test; and (5) encourage students to use English while doing and communicating about science (Carey 1989; Gelman 1994; Linn & Gelman 1986).

We assumed that learning with understanding of scientific and mathematical terms goes hand in hand with learning about the concepts to which the terms refer (Kitcher 1984). Therefore, rather than simply develop new vocabulary lists, we developed a set of curricular materials that combined second language instruction, lessons about the language of science, and concept development. Development of conceptual understanding involves building models, acquiring knowledge about the set of concepts that are related to the core principles of a domain, and learning the causal relations that exist between related concepts (cf. Carey & Gelman 1991; Kuhn 1970). But an ESL instructional program neither can, nor should be expected to replace the regular, secondary-level science courses. Instead, it should teach students enough science for them to want to, and be able to, join regularly-offered science classes in a timely fashion.

As indicated, model building for understanding, either at the conceptual or linguistic level, is most likely to occur when learners concentrate on a topic. The idea is that learning with understanding is more likely to proceed if students have the opportunity to cover a few topics in depth, in a meaningful context. From a pedagogical point of view then, ESL students should be offered an opportunity to explore a few core science topics in depth rather than survey bits of the full range of topics offered in a full science curriculum or in science textbooks. This teaching principle guided our decision to develop topic-oriented units that shared amongst them several scientific themes.

Focusing science-content ESL instruction on a limited set of inter-related topics offers an additional advantage. ESL teachers are likely to be relatively untrained in scientific areas, because they have chosen an other-than-science career path. ESL teachers are as likely as their students to be unfamiliar with current scientific explanations for natural phenomena and to maintain informal scientific theories regarding them. Indeed, there is considerable evidence that informal theories are held even by college students with extensive science training (McCloskey 1983). An in-depth treatment of science topics does require that ESL teachers re-examine and augment their scientific knowledge, but being able to concentrate on a limited set of topics could help make their task more manageable.

In sum, we were challenged to construct new lessons and related materials that both met the school district guidelines and accomplished our goals of interleaving language and science concept learning, all the while relating these to target conceptual structures. A UCLA/Birmingham team came together to take on this task.

Elements of the program

School and students

The first round of the program was implemented at Birmingham High School in the Los Angeles Unified School District (LAUSD), a school with approximately 3,000 students, 20% of whom were designated as LEP. The great majority of the students in the ESL Program spoke Spanish, having come primarily from México and El Salvador. Korean-speaking students comprised the next largest group. However, the program also served students who spoke Russian, Persian, Armenian, Tagalog, Vietnamese, Hebrew, Thai, Cantonese, and Mandarin. A recent accreditation team confirmed our impression that the school had a very good record as regards the rate at which ESL students were redesignated Fluent English Proficient (FEP). The data presented in this report were collected in an intermediate-level ESL2 class taught by the second author during the fall semester of 1991, the first semester in which the program was implemented.

Teachers and mentors

To start, both ESL and Science teachers were invited to participate in workshops. It was essential to us that the science teachers at the High School become familiar with our goals, plans, and curricular needs in order for them to be able to serve as in-house resources to the ESL teachers, especially regarding materials. Additionally, we consulted with the science teachers about the underlying themes of the high school science curricula. The scientific notions that emerged as critical were variability, energy, interdependence and change. Continuing workshops encouraged the involvement of additional teachers.

The program received further support from bilingual mentors. Through the UCLA Community Service Commission, our project was included among the activities of student members of SOLES (Society of Latino Engineers and Scientists at UCLA). SOLES provided 20 mentors per semester to work with the Birmingham ESL students in completing their assignments, responding to student science inquiries, and using the computer lab (which was introduced after the first round of the program), to do their assignments. SOLES mentors worked in teams and visited Birmingham on a weekly basis.

The course materials

As indicated, the data presented in this report were on the first round of the curriculum. This curriculum was composed of 10 units designed to converge on core themes that overlapped conceptually and linguistically with those identified by the science and ESL teachers, researchers, and school system guidelines, including those in the California State Board of Education Science Framework (1990) which listed six major themes, including energy, evolution and patterns of change. Note that several of the unit titles in the curriculum were about energy sources and systems. An effort was made to order materials so that latter lessons could build on earlier ones. The titles of the initial ten units were: (1) Sun; (2) Photosynthesis; (3) Respiration; (4) Local Winds; (5) Temperature and State; (6) Buoyancy and Density; (7) Water Cycle; (8) Food Energy; (9) Organs and Organisms; and (10) Interactions and Ecosystems.

Each unit consisted of:

(1) an *initial reading* designed to focus the student on the core concept(s) of the unit and to provide the linguistic means to respond appropriately to a short pretest for that unit;
(2) a short *pretest* of a representative core concept presented in the initial reading;
(3) for the teachers, a *listing of the core concepts and vocabulary* around which each of the units was built;
(4) a *main reading* that incorporated the core concepts and vocabulary into a text. This was paired with reading comprehension and second language development exercises. The key vocabulary concepts were highlighted in the reading, such as in the following example about the Water Cycle.

If you look at a globe, a map of the earth, you can see that much of the earth's surface is covered with water. You might conclude that there is plenty of water for the living things. But fully ninety-seven percent of the earth's water lies in the oceans. Most of that water cannot be used by living things because it contains salt. The salt would have to be removed before the water could be used.

Only about 3% of the earth's water is fresh, useful to most of the earth's living things. A major part of that fresh water can be found frozen in glaciers (ice rivers in the mountains), and in polar ice caps. Actually less than one percent of the earth's water is available for use. We can find that water under the ground, in lakes, swamps and rivers, and in the air.

Most of the water of the earth is in constant movement. The water moves from one storage area to another. Water *evaporates* from the oceans and *condenses*, forming clouds high in the atmosphere. More than eighty-five percent of the water vapor in the air comes from the oceans. Water also evaporates from the land areas, from lakes, swamps, rivers, and even from plants and animals living on the land. The water in the clouds is fresh water since only H_2O molecules evaporate. The other elements and compounds in the water are left behind.

Precipitation falls from the clouds on the oceans but also on the land. The water that falls on the land can sink into the ground or it can run off forming streams and rivers. Streams and rivers move quickly over the surface of the land and flow back into the ocean within a few weeks. Gravity pulls the water from the higher parts of the land to the lower parts where the oceans are. *Ground water* can remain trapped in cracks in the underground rocks or it can move slowly to lower levels of land. Gravity pulls ground water also. Almost all ground water becomes part of an underground water system. Underground water eventually flows back to the oceans.

(5) a *laboratory exercise* that focussed on the core concepts and included demonstrations and experiments that the students did in groups. For each laboratory exercise, there was a teacher-oriented set of instructions;
(6) a *review* which involved language and concept development exercises;
(7) a short unit *follow-up test* to the item 3 pretest; and
(8) a *journal notebook* where students kept track of their classwork, recorded their experiments, worked on their review exercises, and proposed questions they would like answered. As part of the unit review exercises, students drew concept maps and then wrote up

to ten sentences about these maps. The notebooks served the additional function of providing data bases for several of our analyses of the first round of the curriculum.

The laboratory exercises were designed to satisfy two constraints: (1) to offer an interactive, manipulatory environment that would provide a knowledge-building experience supporting the core concepts of the unit; and (2) to utilize, as much as possible, ordinary materials which were readily available and which were familiar to both the ESL teacher and the students.

The classroom environment

Our decision to have students in groups for some learning activities was based on findings that opportunities to work in groups can facilitate both science learning (Bereiter & Scardamalia 1989; Brown & Campione, in press; Brown & Palinscar 1989) and English language learning (Brown, Ash, Rutherford, Nakagawa, Gordon & Campione in press). Care was taken, when possible, to assign students so that at least one member was not of the same language group as the other members. The mixing of language groups was done to *encourage* the use of English to accomplish the group assignments. After students took each within-unit pretest and post test individually, they discussed their answers in groups in order to produce a consensus response. Laboratory exercises were also completed in groups so as to provide students an opportunity to use English to negotiate meaning, practice using the language of science and help each other understand the material (Brown, et al., in press). For a given unit, each member in a group had a role: chair, speaker, writer, or worker. The worker was responsible for performing the assignments of the laboratory exercises, and for getting and returning materials. The writer recorded the data and results of the exercises and also wrote the group response for the unit pre-tests and post tests. The speaker asked questions and reported results during the class review of the exercises. The chair was responsible for supervising the work of the group and filling in for absent members of the group. With each unit, the roles in the cooperative groups rotated.

The problems of assessment

We turn now to assessment of the program. The nature of the sample presented special challenges for studies conducted in Los Angeles or any other large community facing high rates of immigration.

Almost by definition, such a sample includes extremely mobile students. They are in families recently arrived in Los Angeles and who are often still deciding where to settle down. A majority of the city's ESL students travel long distances to and from school. Those in Los Angeles who attended Birmingham High School spent at least two hours busing from their Central Los Angeles neighborhoods to the school. An additional consideration was the variation in students' educational backgrounds, which depended on, for example, whether a student's family had lived in a city or a remote village in their country of origin. Also, the ongoing budget crises at all levels of state and local government affected the stability of any school program, be it experimental in nature or not. Teachers were moved to different schools and classes were combined. These factors are beyond the control of any researcher and they converge to make designs that require a priori and random assignment of pupils to different groups nearly impossible. Nevertheless, it did not follow that there were no comparisons that could be used for assessment of experimental programs.

Even though the students in our program came from diverse educational backgrounds, it was reasonable to assume that they shared a rather common level of scientific understanding. This followed from our earlier review of the fact that students with extremely different levels of education hold similar misconceptions. Indeed, this is why we decided to assess scientific understanding with extensive in-depth science interviews that were administered in English, Korean and Spanish. They covered topics in the biological and physical sciences with materials and were closely patterned after work by Brown & Campione (at Berkeley) and Carey, Smith & Wiser (at MIT, Harvard and Clark, respectively). Versions of the interviews were administered prior to, and after, the classroom intervention. Of course, the English speaking students were not in ESL. Analyses of these interviews are still in progress. They will provide data for our hypothesis that, despite the diversity of their educational, linguistic and cultural backgrounds, the sample of entering high school students were rather homogenous with respect to their understanding, or lack of understanding, of the key concepts taught in pre-college science classes. The post-intervention interviews then can tell us whether the students in the program at least came to attend to relevant aspects of their curriculum, and if so, whether they achieved a different level of understanding. Concept maps can achieve a similar result. Analyses of the in-depth initial and follow-up interviews can only start after we have transcripts and translations of these. Thus, these kinds of extended assessment plans are still ongoing.

The difficulties described above not withstanding, one must find ways to assess a program. For example, one should ask whether ESL scores of the students in the program stayed level as compared to those not in the program. By participating in the program they get less of the standard ESL curriculum. All pupils who participated in the program took the LAUSD end-of-semester evaluations—multiple choice, discrete-point grammar tests—including those in the classes of two other ESL teachers who used the curriculum in the spring of 1992. These teachers were relieved to discover that student performance was comparable to previous groups they taught; as were we with their reports to this effect.

It also is important to determine whether the students came to attend to, and work with, relevant aspects of the program. Unless learners attend to and use what instructors take to be the relevant aspects of their lessons, it is unlikely that the target learning can take place. In Piagetian terms, learner's tendencies to construct interpretations of inputs depends on their focusing on and assimilating the kind of data that can nurture knowledge growth (Beilin 1992). A related point is made by Stigler and Fernández (in press) who show that sixth grade students who do better at learning the math in new lessons are much more likely to attend to the key parts of a new lesson in a mathematics class. We turn to some considerations of whether our students were more likely to attend to and use relevant material in their lessons.

What do students get from the units?

Performance on unit-specific pre-tests and post tests

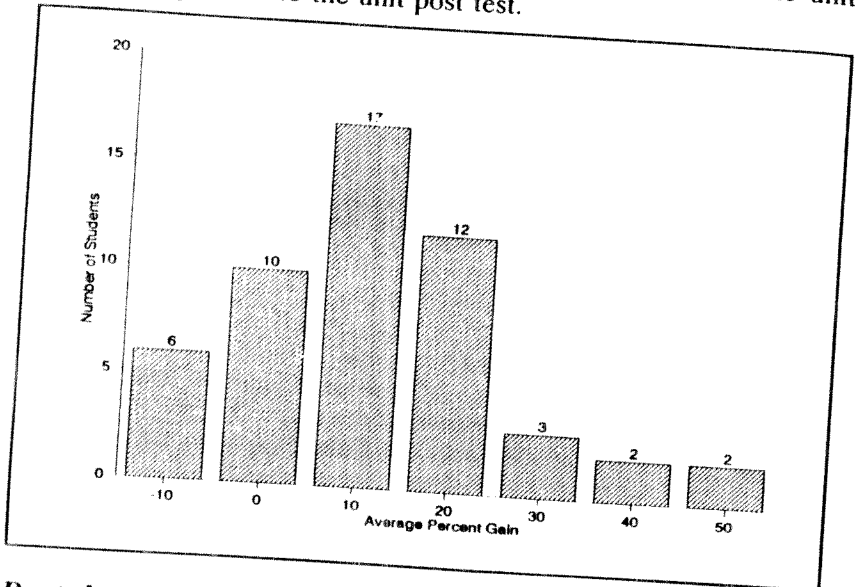
As indicated, students in the program were given a brief pre-test and post test for each of the units. The content of the students' written answers were scored as 2 (correct), 1 (partially correct), 0 (wrong or ambiguous). Students did not have to use correct spelling or syntax to achieve a score of 2 on an item. They did have to use relevant content (see Table 1 below for examples of some of the students initial wrong answers and the kinds of correct answers they could write on the post tests). Ten pre- and post test answer sets were scored by two independent raters. They agreed on 94.5% of their ratings and had no particular pattern of disagreements. They achieved an R-square of .89.

Table 1 Selected student answers to pre-test and post test

A Pre-test Item	*Post test Version of the Item*
On a cold but sunny day, you must wear a jacket to keep warm. Which color jacket will keep you the warmest?: a black jacket? a blue jacket? a red jacket? a white jacket? a yellow jacket?	Which color should the painters use for the hot water tank? Remember, you want to make the water as hot as possible.
Why will that color jacket keep you warmest on a cold, sunny day?	Should the painters use black, blue, red, white, or yellow paint? Why?
Pre-test Answers	*Post test Answers*
Student A I keep a black jacket. ... Because is better for the weather and I like the color, any color is good for me. but I prefer a black jacket. *Score (0)*	*Student A* I paint with black. ... Because, this color absorb the light of the sun. ... If I paint with black, I make the water hot. *Score (2)*
Student B blue jacket. because the blue color is warm but also is cool for a sunny day and also is a color pretty *Score (0)*	*Student B* Black. I think than the black color because this color absorb energy and the water can make hot *Score (2)*
Student C white jacket, ...because this jacket *Score (0)*	*Student C* I paint the black color. I use this color because it this color keep the water hot. *Score (1)*

A total pre-test score and a total post test score were computed for each student who took at least 5 of the paired tests for a unit. After adjusting for the number of paired tests they took, these pre-test and post test scores were compared using a correlated t-test, which indicated that these pre-test and post test scores were reliably different ($t_{53} = 7.3$ $p < .0001$, 2-tail) (see Figure 1, which presents the distribution of students' percent improvements from the pre-test to the post test).

Figure 1 Tendency of students' scores to improve from the unit pre-test to the unit post test.



Do students write about relevant matters?

Students' journal notebooks turned out to serve as a source of data for some analyses of language-for-science use. As a review exercise the class generated 10-20 words considered to be important and relevant to the topic of that science unit. Then they made concept maps with these words. Finally, students were then asked to write at least ten sentences in their notebooks using the words in the concept maps. Individual sentences were not scored for syntactic accuracy. Instead, those who wrote at all received a grade of A; and those who wrote no sentences received F grades. These sentences, therefore, were somewhat like data one gets if students are asked to talk about what they are learning and then these conversations are transcribed for analysis of content-relevant speech. Each sentence or fragment on a line was considered a sentence for purposes of the analyses.

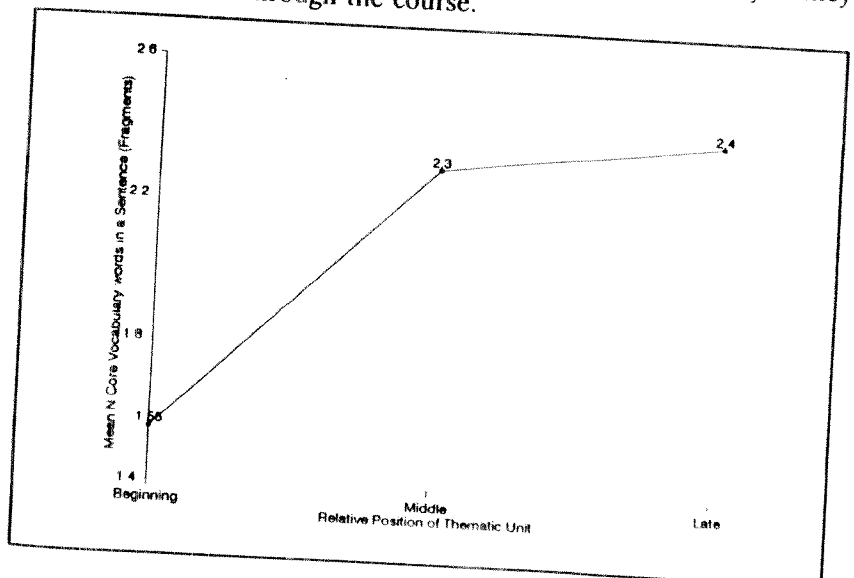
Initially we asked: (1) Do students' tendencies to write sentences using core vocabulary terms increase as a function of the number of science units they are exposed to? and (2) Do students find it easier to write in English, as evidenced by their tendency to write longer sentences? In and of itself, length of sentence need not be a measure of growth. However, if students express scientific ideas, perhaps they

of growth. However, if students express scientific ideas, perhaps they will also write more complex sentences using subordinate clauses. Scientific writing includes statements that express hypothetical and causal relationships, such as, if—then and because statements. These related syntactic devices have a tendency to add length to a sentence.

Core Vocabulary Use

To address the first question, we worked with all of the sentences written by the fall 1991 students when they finished Units 1, 4 and 8 and, therefore, were at the *Beginning*, the *Middle*, and near the *End* of the semester. Each of these sentence was inspected for the presence of core vocabulary items. Then to compute a score, the total number of core words was divided by the number of sentences. On the average, the class used more core vocabulary terms as they progressed toward the middle of the term (see Figure 2).

Figure 2 Tendency of students to use more core vocabulary as they move through the course.



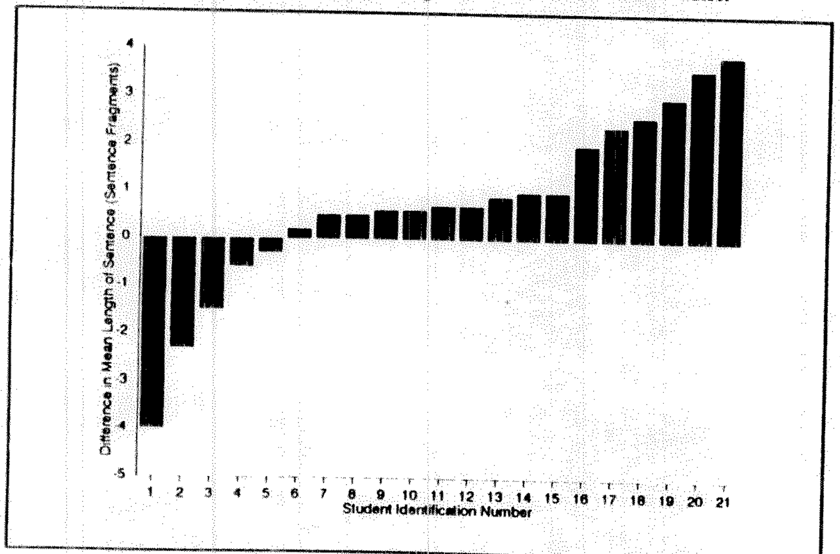
Length of Sentences

Students wrote longer sentences as the course progressed (see Figure 3 which shows the increase in mean sentence length for each student from the first unit to the fourth unit). ...

that a reliable number of students wrote longer English sentences in the middle than in the beginning of the course ($p<.002$, 2-tailed).

We also asked whether the content of these students' sentences became more relevant as function of experience. The 21 students' sentences were scored as to whether or not they correctly described a core concept for a unit (e.g., "Sunlight influences the production of glucose," "The sun gives energy for the photosynthesis") and whether they correctly described another scientific concept that was not central to the unit (e.g., "Water is a compound") (see Figure 4). Early on, students mixed core ideas of a lesson with other scientific content. By the middle of the term, they focused more on the relevant core concepts of a unit. This was further evidence that students focused on relevant information in the curriculum as a function of class experience.

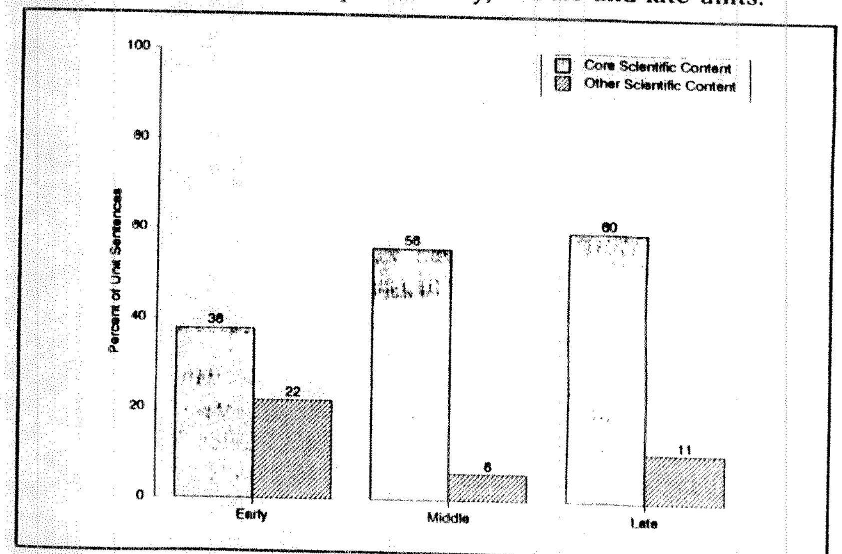
Figure 3 Increases in average notebook sentence length for each student from beginning to an intermediate unit.



We were interested in the ways students expressed their understanding of the ways science terms relate to one another. Because scientific writing involves the expression of different semantic relationships between terms (Lemke 1990), we coded for the different ways that students interrelated terms within sentences. For this analysis, we chose sentences that contained the word "energy" for two

reasons: (1) energy processes constitute a core underlying concept for all 10 science themes; and (2) students generated the word "energy" as an important term in 8 of the 10 unit review exercises. Relationships between science terms regarding energy were classified into one of three categories. The first category, *Simple Fact Statements*, was an attribution sentence used to state properties of objects or propositions, e.g., "The sun has energy." The second category, *Simple Relational Statements*, included statements expressing relations between objects or propositions, e.g., "Plants take in sunlight energy." These sentences generally stated which science terms go together with other science terms. The third category, *Complex Relational Statements*, expressed reasons for, how, or in what way, objects or propositions were related, e.g., "Plants take in sunlight energy to make food." Sentences at this level generally described scientific processes related to a term or concept.

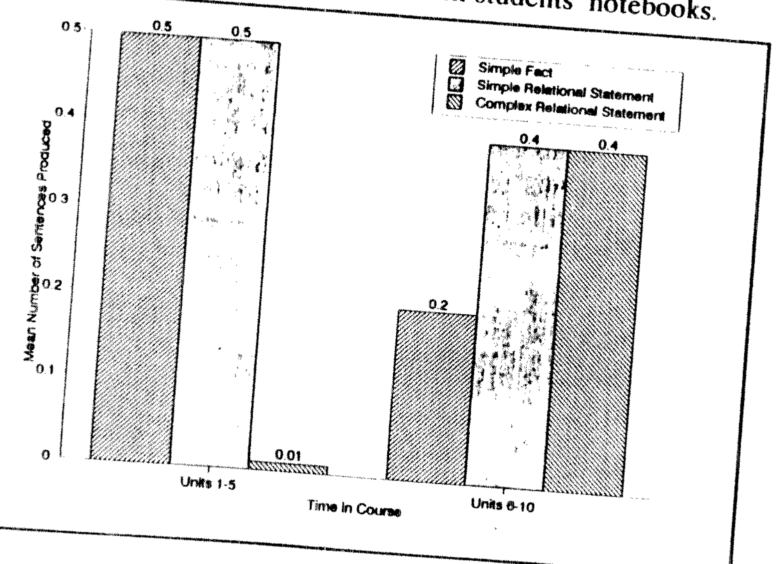
Figure 4 Students' tendencies to write English sentences with core scientific concepts for early, middle and late units.



Students exhibited a qualitative shift in their writing (see Figure 5). Initially, students wrote sentences stating simple attributive facts about energy. By the sixth of the ten units, the students began to write more compl[illegible] [illegible]tional sentences (Romo, 1993)

The above analyses of language use as function of time in the course share a common characteristics. They all point to students' increased attention to, and use of, relevant aspects of the curriculum. As we said above, attention to relevant aspects of input is a prerequisite for learning. Such evidence of students coming to focus on features of both the science and English instruction is important for two reasons. First, it encourages us to pursue further analyses directed at the specific question "Is there longterm learning about science and the language of science?"

Figure 5 Type of relational sentences in students' notebooks.



Second, we believe that these kinds of analyses were of the form that teachers are likely to find useful, ones they too could use to monitor whether their students are "on track." Once identified and carefully described, it should be possible to create translations of these kinds of analyses into brief descriptions for teachers to use. These descriptions would be short and serve as examples of what students' school work looks like if they have been or have not been attending to the aspects of the lessons that teachers care about. A similar point is made by Neimi (1994). In this regard, we note that the pattern of results show that it takes some time for pupils to learn enough to start to perform in task-relevant ways. It is only about halfway into the course that the kinds of things teachers might care about begin to appear.

Inspection of the pattern of unit by unit pre-test to post test scores summarized in Figure 1, rules out a simple interpretation of the pattern of language results. It is not simply that students did better and better as the course proceeded. Difference scores from these unit tests showed that students had an especially difficult time with the Density Unit. This Unit was the sixth in the term. Units that came later were more likely to engage students. For example, they wrote more sentences about their concept maps for units that followed the Buoyancy and Density lessons (Romo 1993).

Were students in the program interested in the science content?

Within the Piagetian framework, affect and knowledge acquisition go hand in hand. Motivation to use the knowledge to gain further knowledge is part and parcel of the individual's constructivist tendencies. If the above analyses were indices of students' attention to, and use of, a growing base of relevant knowledge, there should be some evidence of a related positive attitude toward the course.

A sample of students who were in the program answered questions designed to determine how interested they were in science before and after being enrolled in the course. We are disinclined to present the scores showing positive changes, because we have no control for the possibility that students gave higher ratings after the course to please people they had come to know. Still, the kinds of things that the students said to justify their ratings suggest that, here too, the course had a positive effect. For example, when asked whether the science in ESL was interesting, individuals gave these kinds of answers:

(1) "Because the teacher explained it to us very well."
(2) "We did many interesting experiments."
(3) "I was able to do experiments and was able to learn new things I didn't know."
(4) "Because I have learned more about science than what I had imagined."

We also asked whether a given student would recommend ESL with science to other students and why. Again, the explanations are interesting:

(1) "Because other classmates that have not been in a science class before would be given the opportunity to learn something new about this."
(2) "It is because I like it more when students study together. Then if we have a problem, we can talk with the other students."
(3) "One learns science and English at the same time."
(4) "In regular ESL class, we really don't converse with other people, but in ESL science class, we can talk to one another."
(5) "They would use it a lot when they are in university and it can help them a lot."

Don Operario's diary from his fall 1992 classroom field study contains corrorbative notes. In October, he wrote:

> I found that this experiment (about the sun as a source of heat) was very useful to the students. I was surprised at how many students did not know about heat and measurement. I'm glad many of the students were able to learn how to use a thermometer. But I am especially happy to see the students actually having fun while learning. Even the students in the "shade" condition, when asked, said they were enjoying the experiment.[2]

Operario's final entry corroborated our conclusion that students came to attend to the science content of the course.

> The program's strength lies in the interest of the students in the materials, which is obvious in all of the classrooms. I believe that if the students are further encouraged to take an active role in their learning through programs such as this, their educational futures will be much brighter.

We agree with this assessment, although we recognize that many challenges lie ahead before these conditions are met.

Discussion and summary

We have developed the argument that learning about the language of science goes hand in hand with learning about scientific

[2] Students who took measurements for the *shade* condition were gathering data for the control condition and were getting same temperature readings time after

concepts and the methods of science. The idea that there is a deep relationship between the relevant language and concept learning led us to suggest that programs for ESL students embed learning about science and the language of science into instruction about English. This is a way to avoid delaying the point at which ESL students start learning about the content and tools of science. Given the added concern that an ever increasing number of career paths require considerable technical and scientific literacy, it is especially important to find ways to offer ESL students relevant schooling options, especially when the majority language no longer is English.

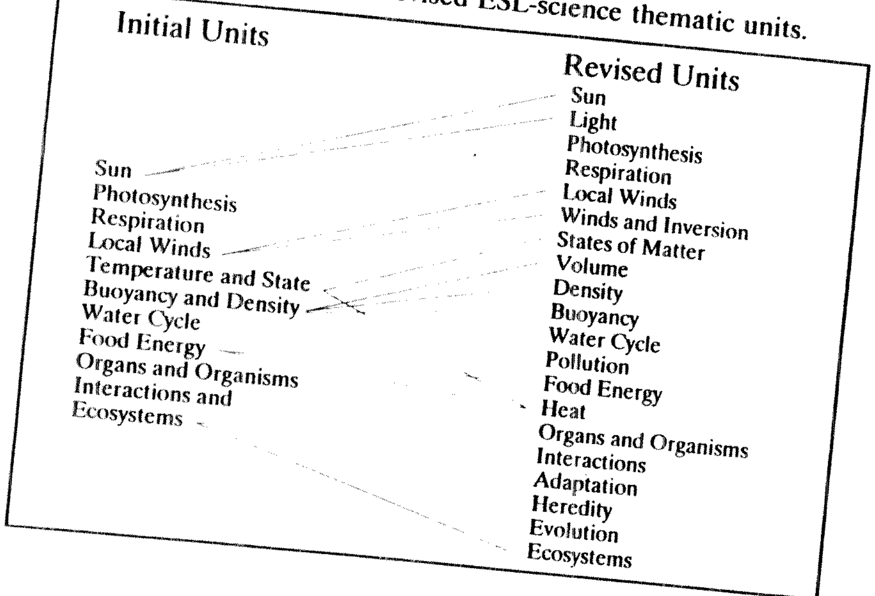
We have presented our initial effort to develop a science-in-ESL high school curriculum that takes advantage of the lessons of cognitive science. Our commitment to assessment led us to seek ways to acquire on-line learning indices, ones that tell us whether students come to attend to and use relevant aspects of the curriculum. Some aspects of our data encourages us to think that programs like ours can serve to foster acquisition of language skills of the kind to do, and learn about science. Still, it is clear that much has to be done to achieve this goal. A key item for work includes further development of the curriculum.

We obtained evidence that the Density and Buoyancy unit was too hard for the students: they had low post test scores and wrote very few sentences in their notebooks during the concept map review exercise. Meck found out that there was too much material to teach in some units, for example the one on the Sun. For still other units, it became clear to him that key concepts were not being covered. This was especially true for the Interactions and Ecosystems unit, a key one from our point of view since it deeply involved themes of Change, Variability, and Interaction. These considerations led Meck to expand the initial 10 units into the 20 units listed in Figure 6. The connecting lines between the set are meant to reflect the ways use of the curriculum provided feedback for the kinds of units that needed to be added.

Other items on our list of must-do's are ones that ensure that our program or close variants of it can be used by ESL teachers even if we are not involved. We are especially concerned to respond to teachers requests for help teaching science. To this end, we have prepared samples of teacher-oriented support materials. These include videotapes of ongoing classes that show key ingredients of the program, e.g., relevant instruction about the experiments students

We also have explored ways to link the teachers and students to computer systems that are paired with mentors and other people who can answer questions, provide suggestions, and so on. This motivated the effort to establish a small computer laboratory for the ESL program and link it to local university computer-based electronic communication networks.

Figure 6 The initial and revised ESL-science thematic units.



Much remains in the way of assessment and development before we can say that we have achieved our goal of implementing the cognitive lessons to assure that all students—no matter what their linguistic or cultural origin—are set on learning paths that lead them to technical and scientific literacy. Still, we are encouraged to continue.

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