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ABSTRACT

Reported is a study based on the summary findings of a series of studies which indicated that many children who receive organized instruction designed around the few major concepts of science do, in fact, use scientific models to explain their observations of natural phenomena. The instruction that children in the study received was delivered by means of an audiotutorial (A-T) science program, the design and planning of which were based in part on the educational psychology of David Ausubel. Background information about the Audio-Tutorial Elementary Science Project (ATESP) is presented. A carrel set-up picture for one A-T science lesson is presented and described. The method of inquiry chosen included the use of Piaget's revised clinical method for interviewing and is described in detail. Concept maps are presented, serving as guides for interviews dealing with the various concepts. Data are presented for 95 children who were present for all of the four interviews conducted as part of the program. Conclusions drawn project positive results. (Author/EB)

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**CHILDREN'S CONCEPTS OF NATURAL PHENOMENA:
USE OF A COGNITIVE MAPPING APPROACH TO
DESCRIBE THESE CONCEPTS**

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Anderson asked if children *could* formulate scientific models:

This study is an attempt to determine the extent to which children are able to formulate mental models to explain their observations of natural phenomena.

This paper begins by accepting the summary findings of a series of studies^{4,7,8} which indicated that many children who received organized instruction designed around the few major concepts of science *do use* scientific models.

A model is defined here as a set of meaningfully connected concepts therefore the attention of this study was directed upon the use of such concepts by elementary school children. The essence of the study is embodied by the three research questions asked:

- (1) How typical of the larger population of elementary school children are the concepts used by children in this study group?
- (2) What is the nature of the major scientific concepts and models used by instructed children to describe several natural phenomena?
- (3) Does a clinical interview followed by a novel evaluation form provide an adequate description of these models?

The organized instruction that children in this study received was delivered by means of an audio-tutorial science program, the design and planning of which were based in part upon the educational psychology of David Ausubel³; lesson content and sequences *tend* to present ideas in a hierarchical fashion with superordinate concepts serving to facilitate learning of new and subordinate concepts. The effect of learning new subordinate concepts in turn adds new meaning to the superordinate concept. In this study the description of a superordinate concept is in fact the number, the degree, and the richness of its subsumed elements. We are advocating a hierarchical view of concept learning.

It must be stressed that *concept hierarchies* here refers to a complex and dynamic process of cognitive differentiation with subordinate concepts being incorporated into the cognitive structure of an individual. While this view of learning, derived from Ausubel, does not directly contradict the learning hierarchy view of Robert Gagné⁵ summarized as:

Thus it can be seen that rules relevant to a specific science topic require the prior learning of subordinate rules that are *general* to science, in the sense that they deal with the *processes* of obtaining scientific information, whether this is biological, physical, chemical, or whatever. Moreover, these fundamental rules necessitate the learning of prerequisite concepts. It would be possible to show that these latter concepts also depend on simpler forms of learning . . . [p.264]

it must be seen as richer, and more capable of explaining concept learning than the very directional and absolutist view presented by Gagne.

BACKGROUND.

From 1967-72 science curriculum development work at Cornell University resulted in the production of over sixty audio-taped, individualized, elementary school science lessons, under a project entitled the Audio-Tutorial Elementary Science Project (ATESP). The goal of the ATESP lessons is to facilitate the learning of important basic science concepts. By 1972 these lessons had been tested extensively with more than six thousand first, second, and third grade children in upstate New York, as well as in Indiana, Connecticut and several other locations. During the lesson development phase the Program was fortunate in having input from a succession of persons, each of whom had not only a strong academic background in one of the sciences but also an excellent grasp of the conceptual structure of his/her respective discipline. Although the existing audio-taped lessons make continual use of props, toys, pictures, film loops, and ViewMaster reels the organizational theme is always a recurring conceptual description of the natural world. Figure 1 shows materials for one lesson as they are set up in the carrel.

Major concepts treated include ENERGY, CONSERVATION, CONTINUITY OF LIFE, HEAT, KINETICS, STATES OF MATTER, PARTICULATE NATURE OF MATTER, GRAVITY, THE UNIVERSE, POPULATION DYNAMICS, and ECOSYSTEMS. Titles of all lessons are included as Appendix A. McClelland⁷, Hibbard⁶, and Nussbaum¹⁰ described the approach to development and assessment of instruction for some of these concepts. Postlethwait, Novak, and Murray¹² described the general approach to audio-tutorial instruction.

Within the constraints of the cassette-taped mode an attempt has been made to allow children to procede at a variable pace through systematic instruction and to allow for their progressive differentiation of major science concepts. Progressive differentiation in the lesson scripts can be

seen as a continual attempt to show relationships of subordinate concepts to more inclusive ideas, thus causing superordinate ideas to become richer as new information is added.

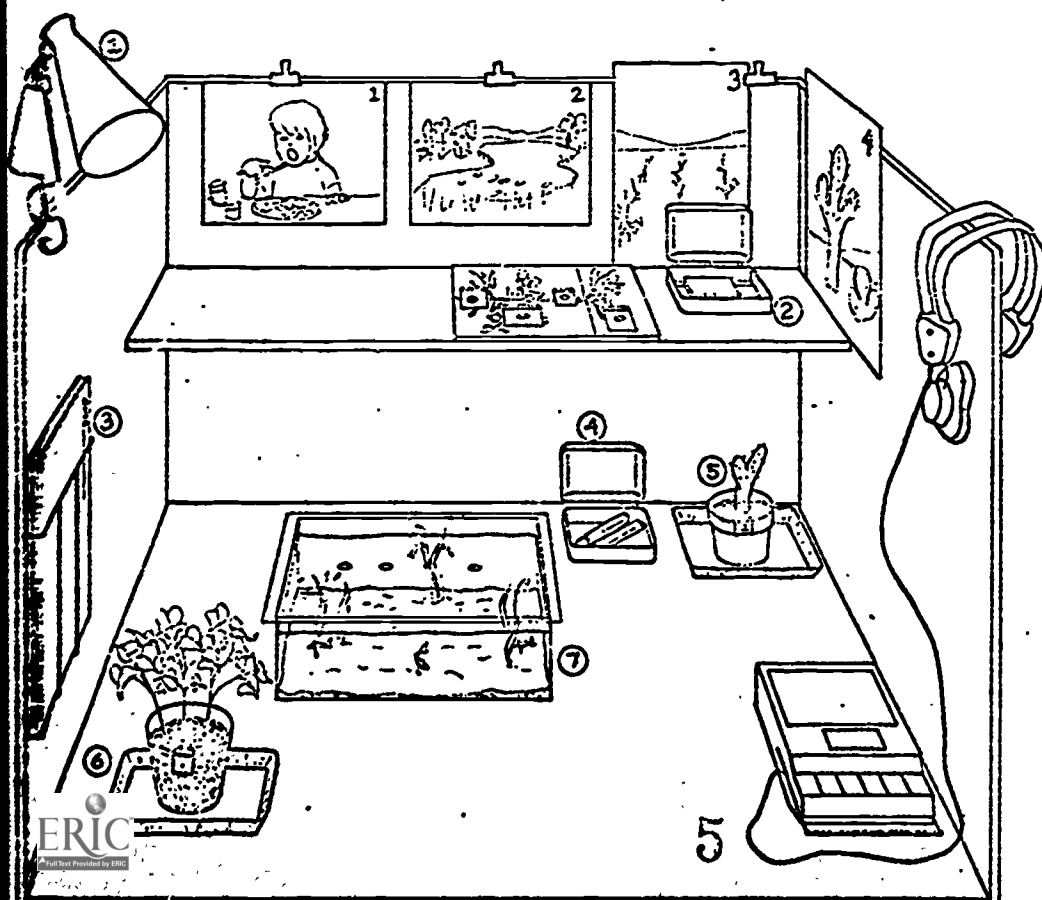
Most lesson evaluation done up until 1972 indicated that the major proportion of participating children had mastered the concepts involved. For example, Hibbard⁶ found that ninety percent of the children instructed in particulate nature of matter used a particulate description for smells while none of the uninstructed children described a smell that way, and seventy-one percent of the instructed children suggested acceptable solutions to a transfer of knowledge problem while only thirty-two percent of the uninstructed children did so. His study, as well as the others completed by 1972, used both one-to-one interviewing and group-administered paper-and-pencil tests to determine mastery.

Figure 1. A carrel set-up picture for one A-T science lesson.

Level II - Lesson 18

Teacher notes:

1. Light for bean plant and aquarium - be sure light is on during the day.
2. Puzzle parts should be in the red plastic container.
3. Worksheets - one for each student.
4. Crayons - one yellow and one blue.
5. Cactus plant from Life Station - clip the number 2 on the pot and water the plant.
6. Bean plants in clear plastic pot from Life Station - clip the number 1 on the pot and water the plants.
7. Aquarium from the Life Station - keep the top on the aquarium and feed the fish.



In September 1971 all of the first grade children in four Ithaca City School District elementary schools began using ATESP lessons. By the end of the 1973-74 school year ninety-five children from the original group still remained and had completed an entire sequence of forty lessons. The four elementary schools involved are "average" upstate New York schools. The Ithaca City School District incorporates not only city schools, but suburban and rural schools. The rural schools were annexed to the district within the last decade. All schools to some degree have a student population reflecting the nature of the area's major employers: two institutions of higher education, two major manufacturers and a diversity of smaller industries. No evidence will be given here to demonstrate that the children in this study are representative of a larger population, however many informal comparisons strongly suggest that the performance of these children is typical of other learning environments as dissimilar as a migrant farm worker district and a rural Indiana school district.

METHOD OF INQUIRY.

The method of investigating children's concepts that was chosen in this study included the use of Piaget's revised clinical method for interviewing. For each interview six to ten general guiding questions were written using the ATESP lesson scripts as the content source. Appendix B lists these questions for one interview. All questions make reference to some piece of apparatus presented to the child during the course of the interview. All interviews were audio-taped. Some were video-taped. Figure 2 shows a second grade girl being interviewed and audio-taped.

Children individually volunteered to leave their classroom - where the A-T carrel was typically located (Figure 3 shows a boy doing a lesson in his classroom) - to go to another location in the school building for each interview. All interviews began with a statement by the interviewer: "I'm going to ask you some questions about things that were in the science booth just to see what you have to say about them." The interviewing schedule typically began two weeks after a sequence of lessons emphasizing the relevant concepts had been completed by all children in one classroom. Five interviewers were used, although seventy-five percent of the interviews were conducted by the principal investigator.

In addition to the guiding questions interviews were structured around "concept maps". These maps were produced as postulated hierarchical relationships between the science concepts being taught. These maps shown in Figures 4-6 were not meant to be either exhaustive or exclusively precise. Their function during the course of the interview period was to direct attention toward eliciting the child's version of the relationships between science concepts. Their function during analysis of interviews is described during a later section of this paper.

A concept map is a diagram of the key concepts in a discipline with meaningful positioning on the vertical dimension. Concepts of about the same level of generality appear at about the same vertical level. The possibility of many concepts appearing at the same vertical level gives the map its horizontal dimension. At the lowest level on the vertical will appear the events to which the concepts refer. The relative positioning and the connections that are made represent the map-maker's view of the

Figure 2. A child being interviewed regarding states of matter.



Figure 3. A first grade boy doing an A-T lesson on transformation of energy.



discipline. Any one concept map serves as only one way of organizing the knowledge in a discipline.

Some tests which must be met by a concept map are: does it describe events in a way consistent with those events, is it helpful in illustrating a complex aspect of a discipline, and does it suggest ways of conducting inquiry in the discipline.

Concept maps in this study are essentially one dimensional. That dimension (the ordinate) indicates degree of inclusiveness. Concrete exemplars are placed at the bottom of the ordinate, and the most inclusive concepts ("powerful superordinate concepts") are placed at the top. Relationships indicated are therefore hierarchical.

A second dimension of a concept map is implied, although not specified. Along the abscissa concepts are placed so that those immediately differentiated portions of the same superordinate concept are close together while those that are more remote are placed further apart, horizontally. In practice, because priority is given to the hierarchical ordering it is not always possible to demonstrate the desired horizontal relationships, so this axis must be interpreted more loosely.

Emphasis is given in the maps to the ordering of concrete examples, primary concepts, and secondary concepts. Ausubel³ defines *primary concepts* as:

. . . those concepts whose meanings a given individual originally learns in relation to genuine concrete-empirical experience, that is, those of his concepts whose criterial attributes, whether discovered or presented, yield generic meanings during learning when they (the attributes) are *first* explicitly related to the exemplars from which they are derived, *before* being related alone to his cognitive structure. [p.198]

In this study concepts are being ordered according to similar considerations. On the map, primary concepts are those most immediately above concrete examples. Secondary concepts are all of those more inclusive concepts at higher vertical levels. Ausubel² further commented on the relationship between concepts and concrete empirical experience:

The primary school child is by no means dependent on *immediate* concrete-empirical experience in understanding and manipulating simple abstractions or ideas about objects and phenomena. It is true, of course, that the emergence of such ideas must always be preceded by an adequate background of direct, non-verbal experience with the empirical data from which they are abstracted. But once their meaning becomes fully established as a result of this background of past experience, the child can meaningfully comprehend and use them without any *current* reference to concrete-empirical data. [p.261]

As noted earlier, the ATESP science lessons were designed to present basic science concepts through carefully planned activities; therefore it was possible to extract from sequences of lessons the major and subordinate concepts taught and to produce concept maps such as those in Figures 4-6.

Concept maps have their origin in the structure of the discipline. The view underlying this study is that science is a conceptual system, a conceptual system with which humans attempt to make sense of natural phenomena. This view is consistent with Roller³: "Science is not concerned with things, it is concerned with ideas, although these ideas often are ideas about things. And those ideas are created by men's minds;" Nash⁴ "Science is a way of looking at the world;" Voelker⁵ "Science is thus a human activity by which organized knowledge is acquired about the immediate environment, the earth and the universe;" and NSTA⁶ "The scientific enterprise can be interpreted as consisting of three major subsets. These are: (1) the observation and description of nature, (2) trying to understand nature rather than trying to seek out its detailed structure, and (3) technology."

A concept map for a portion of science is therefore an ordered listing of the concepts used in that branch of science to make sense of its particular phenomena of interest.

The procedure for constructing a map requires that the discipline serve as a source. The ideal is that the map be constructed compatible with the arrangement of concepts within the cognitive structure of the leading scientist, or group of scientists, representative of that branch of science. In operation, construction must most often be based upon the writings of such scientists, contemporarily acceptable textbooks and other cognitive structure representations.

Figure 4. Concept map #2. This map serves as a guide for Interview #2, dealing with a continuity of life model.

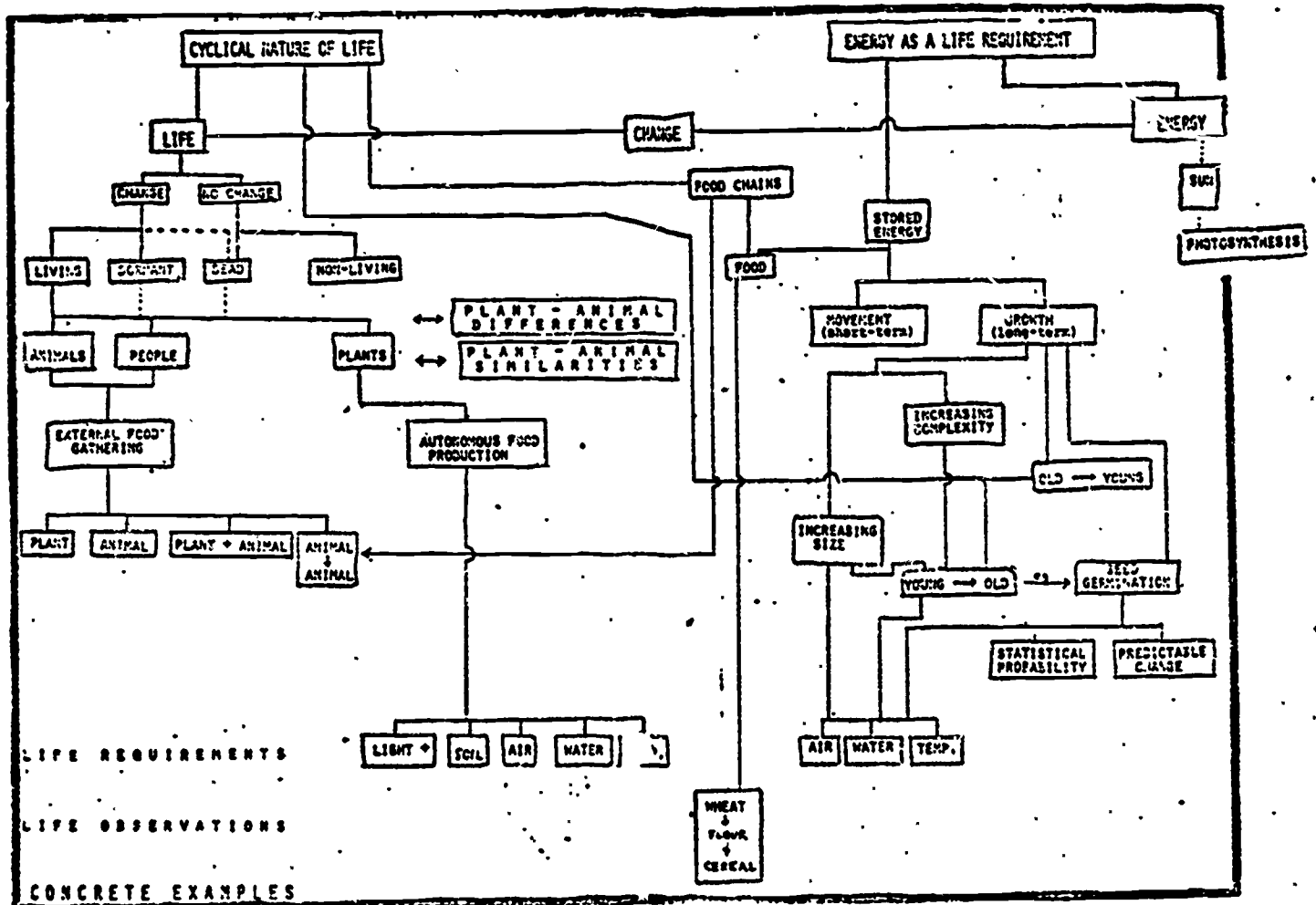


Figure 5. Concept map #3. This map serves as a guide for Interview #3, dealing with a particulate nature of matter model.

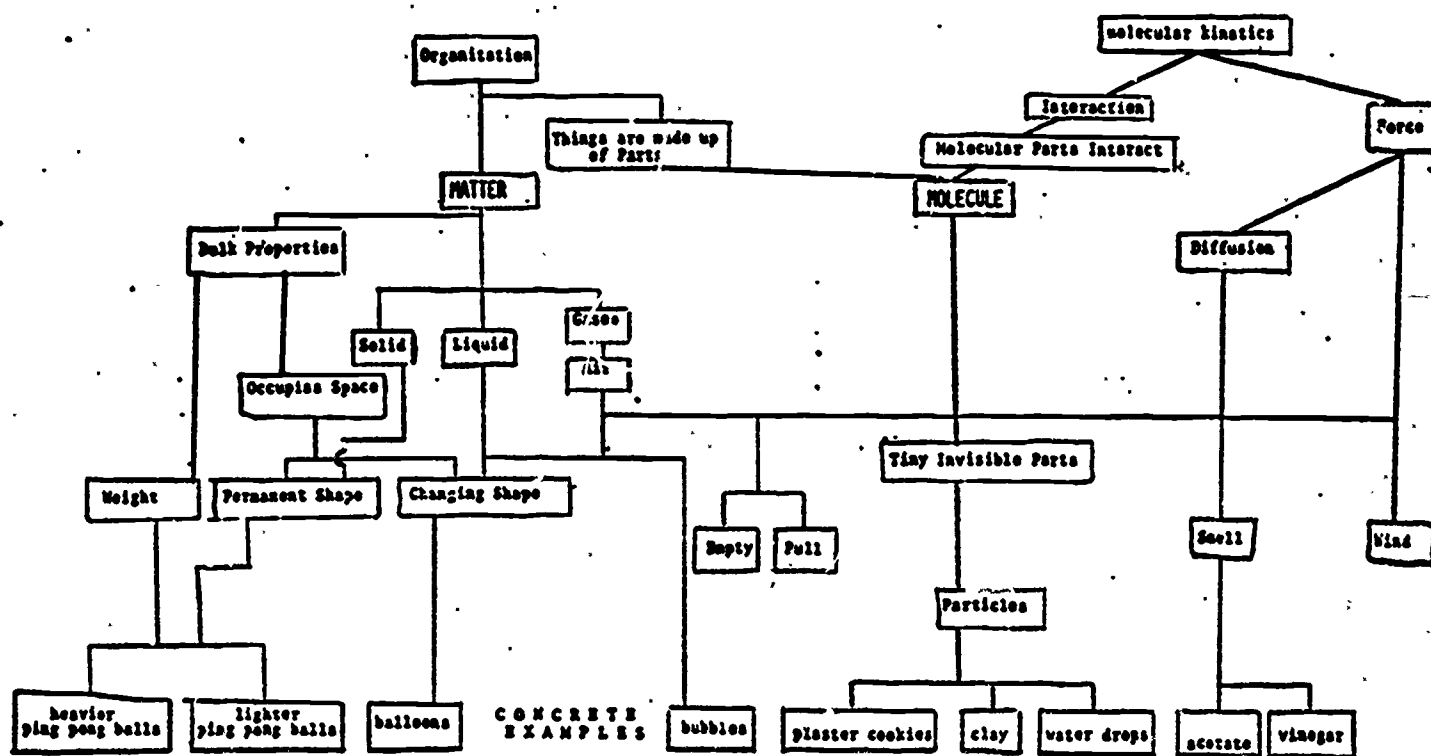
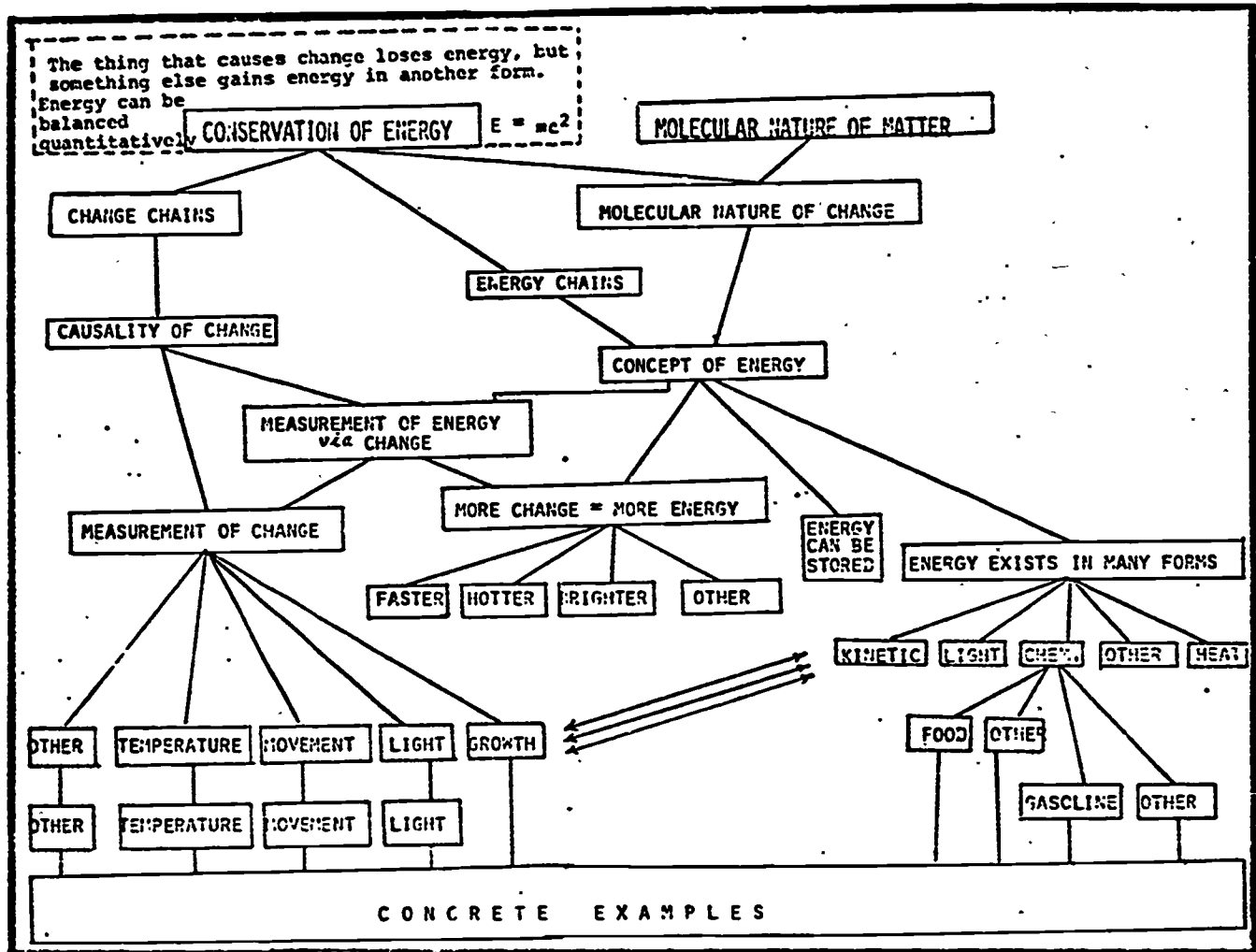


Figure 6. Concept map #4. This map serves as a guide for Interview #4, dealing with an energy model.



In the present study two additional sources were utilized. First, some exploratory interviewing with children in the same age group and with the same background as the ATESP children was conducted. (Most of these trial-phase children were in the same classrooms as the experimental group, but had entered the school district after October of the first grade year. Many had also been doing the A-T lessons for at least one year.) These children served as indicators of the concepts present in the population.

Second, the ATESP scripts were analysed, not only for concepts but also for the language in which the concepts were presented. For example, the concept of a *cycle*, as applied to continuity of life, is included on concept map #2 (Figure 4). This concept is perhaps not representative of the cognitive structure of leading biologists as it implies negative biological time, a continual return to the same point; nevertheless, a *cycle* nature of life was included in the map, and did guide the interview questioning. Trial interviews failed to reveal acceptable alternative concepts for the continuity of life, and the cycle concept had been presented to the ATESP children.

Although two limitations were imposed upon the construction of concept maps in this study (i.e., "which concepts can be expected to be found in this population of first, second, and third grade children?", and "for which concepts had an attempt been made to provide instruction?"), the limitations also aided in delineating the content of the concept maps. Those concepts that children develop without organized instruction have been described by Vygotsky¹⁶ as *spontaneous concepts*; those that appear only after active instructional intervention he has described as non-spontaneous or *scientific concepts*. Piaget⁷ has also dealt with the dichotomy.

Protocol for construction of a concept map includes attention to spontaneous concepts, scientific concepts, relationships, and referents, production of a tentative version, and revision of this version by one or more specialists in the relevant conceptual domain.

In this study several persons in the Physics Department as well as the Biological Sciences Departments provided critical comments on draft versions of the concept maps. Other Science Education personnel currently

working on their own mapping projects provided similar advice.

A total of 419 interviews with instructed children were recorded. The length of the interviews ranges from twelve to twenty-five minutes of dialogue. All interviews were first rated on an ordinal scale adapted from Smith¹⁴ and Hibbard⁶. As each interview was constructed around a few powerful concepts, which should subsume other concepts, a *model* approach was used. In the ordinal rating categories "model" indicates the child's verbal use of these powerful concepts accompanied by his/her indication that additional information is subsumed.

All interviews were assigned to one of nine rating categories shown in Figure 7. Twenty-three recorded interviews were listened to by a co-rater; for these a co-rater reliability coefficient of .915 was achieved. In only two instances did the two raters differ by more than one category.

Figure 7. Rating categories used for analysis of interview tape recordings.

RATING CATEGORIES

- | | | |
|--------------|---|---|
| MODELER | { | 1 - Uses model throughout interview |
| | | 2 - Learns model during course of interview and thereafter uses it consistently |
| | | 3 - Uses the model sometimes (in at least 50% of the appropriate situations) |
| TRANSITIONAL | { | 4 - Uses parts of the model throughout interview |
| | | 5 - Learns parts of the model during interview and thereafter uses those parts consistently |
| | | 6 - Uses parts of the model sometimes (at least 50% of appropriate situations) |
| NON-MODELER | { | 7 - Mechanistic explanations - no model |
| | | 8 - Concrete/Observational explanations - no model |
| | | 9 - Animistic/Artificial explanations - no model |

"THE MODEL"

INTERVIEW TWO - Continuity of Life

INTERVIEW THREE - Particulate Nature of Matter

INTERVIEW FOUR - Transformation of Energy

As the goal of this study was to investigate the nature of concepts used by children instructed *via* a specific science program, concept maps were produced based upon the ATESP lessons. These concept maps contain three essential components: concepts, referents, and relationships. The notion of a concept here is that of a sign or symbol that points to a regularity in interpreting events.

The mapping in this study was an attempt to represent children's versions of concepts and relationships for which they had received systematic instruction. Such maps, when they are individually generated in reference to the conversation of a child during a clinical interview, are referred to as *cognitive maps*.

Because the focus of school learning is typically on verbal behavior those referents by which children reveal their concepts cannot be overlooked, however, when the instructional goal is the teaching of concepts, or when the evaluation goal is to identify children's concepts, then the referents are instrumental and cannot be exhaustively specified. Unfortunately, all too often in school learning the referents *are* specified and become the measurable quantity with concepts being either assumed or ignored. We feel that when the intended terminal behavior is concept mastery, then an approach which clearly specifies behavioral objectives may be inappropriate, and we are further concerned that the use of amplified behavioral objectives is yet another step in the wrong direction.

RESULTS.

Although four interviews were conducted with each child, the first interview was not included for analysis in this study as it was brief (usually less than ten minutes) and overlapped with conceptual areas under investigation in interview four. The number of actual subjects for each interview decreased from 191 (Interview #1) to 168 (Interview #2) to 156 (Interview #3) to 95 (Interview #4) because of movement within as well as out of the Ithaca City School District, and because of loss of some subjects in classrooms where the lesson sequence did not proceed at an acceptable pace. In this study data is shown only for the 95 children who were present for *all* interviews.

Table 1 indicates the distribution of ratings for three interviews. A group of children similar in age (seven, eight and nine years old) to the study group children also took part in interviews. The interviews with *uninstructed* children were slightly modified as reference could not be made to activities that had been carried out in the A-T lessons. Table 2 includes the distribution of ratings for three interviews with the seventeen uninstructed children who were present for all three interview dates.

Table 3 shows a comparison of mean rating categories between the study group children and the children who were not doing ATESP lessons.

In this study 285 cognitive maps were constructed based upon the interviews conducted with each of the ninety-five children. Although each interview as an entity was used to assign the child's responses to one of nine rating categories, the maps were also used to indicate each child's versions of concepts of natural phenomena as well as relationships between such concepts.

An attempt to quantify the cognitive mapping would run counter to the intent of this study - to describe in detail greater than that allowed by the ordinal rating categories the scientific models used by instructed elementary school children.

Easley⁴ argued for focusing attention on revealing portions of an interview in addition to categorizing:

When a psychologist interviews a subject, he may be tempted to think of the conversation in terms of the common meanings he shares with the subject. In the process of interpretation, he imposes his own categories on the protocol. This may be necessary

Table 1. Distribution of scientific model use rating categories from three interviews with ATESP instructed children.

RATING CATEGORY	CONTINUITY OF LIFE		PARTICULATE NATURE OF MATTER		ENERGY		TOTAL	
	INTERVIEW #2		INTERVIEW #3		INTERVIEW #4			
	n	%	n	%	n	%	n	%
Modeler	1	27 28.4	17 17.9		19 20.0		63 22.1	
	2	8 8.4	7 07.4		5 05.3		20 07.0	
	3	22 23.2	19 20.0		19 20.0		60 21.1	
Transitional	4	17 17.9	15 15.8		21 22.1		53 18.6	
	5	2 02.1	5 05.3		0 00.0		7 02.5	
	6	7 07.4	13 13.7		9 09.5		29 10.2	
Non-Modeler	7	5 05.3	9 09.5		11 11.6		25 08.8	
	8	4 04.2	5 05.3		8 08.4		17 06.0	
	9	3 03.2	5 05.3		3 03.2		11 03.9	
MODELER	57	60.0	43	45.3	43	45.3	143	50.2
TRANSITIONAL	26	27.4	33	34.7	30	31.6	89	31.2
NON-MODELER	12	12.6	19	20.0	22	23.2	53	18.6
	N = 95		N = 95		N = 95		N = 285	

Table 2. Distribution of scientific model use rating categories from three interviews which children not using ATESP lessons.

RATING CATEGORIES		CONTINUITY OF LIFE		PARTICULATE NATURE OF MATTER		ENERGY		TOTAL	
		INTERVIEW #2		INTERVIEW #3		INTERVIEW #4			
		n	%	n	%	n	%	n	%
Modeler	1	3	17.6	1	05.9	2	11.8	6	11.8
	2	0	00.0	0	00.0	0	00.0	0	00.0
	3	5	29.4	1	05.9	2	11.8	8	15.7
Transitional	4	2	11.8	3	17.9	1	05.9	6	11.8
	5	0	00.0	1	05.9	0	00.0	1	02.0
	6	2	11.8	2	11.8	2	11.8	6	11.8
Non-Modeler	7	1	05.9	2	11.8	5	29.4	8	15.7
	8	2	11.8	3	17.6	3	17.6	8	15.7
	9	2	11.8	4	23.5	2	11.8	8	15.7
MODELER		8	47.1	2	11.8	4	23.5	14	27.5
TRANSITIONAL		4	23.5	6	35.3	3	17.6	13	25.5
NON-MODELER		5	29.4	9	52.9	10	58.8	24	47.1
		N = 17		N = 17		N = 17		N = 51	

Table 3. The mean scientific model use rating category for instructed and uninstructed groups, with the t-statistic for the means of each interview.

	Instructed		Uninstructed		t =	d.f.	*
	Mean	S.D.	Mean	S.D.			
INTERVIEW #2	3.40	2.24	4.65	2.70	2.03	110	p < .05
INTERVIEW #3	4.20	2.38	6.29	2.37	3.31	110	p < .01
INTERVIEW #4	4.13	2.40	5.94	2.51	2.22	110	p < .01
TOTAL	3.91	2.37	5.63	2.63	2.84	334	p < .01

* one-tailed

in starting a new theoretical approach. However, Piaget's concept of cognitive structure (especially of "schemes") now opens the possibility of interpreting regularities in the subject's behavior in terms of structural relationships which account for these regularities by their own dynamic tendencies. Sometimes a brief part of the interview will suggest a key structure, but to make it more than an intelligent guess other parts of the interview, involving major variations in situations and possibly counter suggestions, must also be shown to be accounted for by that same structure.

It is in this direction that analysis of the 285 interviews with ATESP children has been continuing. Selected portions of this analysis are reported here. It is expected that the accumulation of insights provided by a mapping approach will eventually reveal even greater understanding of children's uses of natural phenomena concepts than the categorization technique has yielded in the past. The cognitive mapping process is cumbersome and does not readily lend itself to quantitative manipulation, however these limitations are considered acceptable in the present study. Easley⁴ noted that:

The overriding quest for reliability, which appears to be the dominant concern in the test paradigm is doomed to generate many errors in the identification of cognitive structures. Analysis of protocols, on the structuralist paradigm, is necessarily a slow and nonmechanical procedure. It begins in subjective, but hopefully educated, judgements and moves towards objectivity as it attains completeness in accounting for the total protocol.

Throughout the three-year interviewing period we continually found children using scientific models to explain natural phenomena. Many used sophisticated scientific concepts to order information presented to them during the interview. The following dialogue is offered as evidence that the particular child has and uses a powerful life science concept: [Child's speech in upper case letters]

Interviewer: Here I have some pictures of corn, a girl, some chickens and the sun. Could you use these pictures to tell me a story?

Peer S.: YOU MEAN ABOUT CHICKENS? SHOULD I PUT THEM IN ORDER?

Sure, whatever kind of story you want.

WELL, YOU SEE THESE CHICKENS ATE THE CORN, AND THAT WAS OKAY CAUSE THE CORN USED TO BE GROWIN' IN THE SUN.

I don't understand what the sun has to do with the chickens.

OH, WELL, CHICKENS DON'T NEED SUN . . . WELL, THEY DO, I GUESS, BECAUSE IF THE SUN DIDN'T SHINE ON THE CORN, THE CORN WOULDN'T HAVE ANY STUFF . . .

Stuff?

YEAH. THAT ENERGY FROM THE SUN. THE SUN MAKES THE CORN GROW. AND THE CORN MAKES THE CHICKENS GROW. AND THEN . . . OH, YEAH. THAT'S IT. YOU SEE THE GIRL EATS THAT CHICKEN AND SHE GROWS. THAT'S WHY THEY ALL GO TOGETHER.

Like a chain?

A WHAT?

Like a chain? .

NO, NOT REALLY. OH, I DON'T KNOW WHAT YOU MEAN.

Some people say that this chicken eating the corn and then that girl eating the chicken is like a food chain. Does that make sense?

NO. NOT A CHAIN.

What then?

WELL, LIKE I TOLD YOU. SEE THE SUN GIVES US ENERGY, BUT MOSTLY IT GIVES ENERGY TO PLANTS. AND THESE CORN PLANTS KEEP THAT ENERGY. WE CAN GET IT. SO CAN CHICKENS. WHOEVER EATS IT, WELL, THEY'RE THE ONES GETTING ENERGY.

From the sun?

YEAH, IN A WAY.

And you wouldn't call that a *food chain* from the sun to the chicken to the girl?

I GUESS YOU COULD, BUT IT WOULD BE KIND OF SILLY.

In spite of Peer's disapproval of referring to this concept as a food chain we have credited him with possessing and using a food chain concept. He has given evidence to demonstrate his understanding that energy flows from the sun, through plants, animals, and to secondary consumers. His original instructions were to tell a story. He chose the

story line that focused on energy flow. Peer continued this approach to answering other life science questions during the interview which lasted for eighteen minutes. His performance was rated as category 1 - that is he was using a life continuity model to answer questions throughout the interview.

The following dialogue is not atypical of children who do *not* use a model to answer questions throughout the interview:

Interviewer: Here I have some pictures of corn, a girl, some chickens, and the sun. Could you use these pictures to tell me a story?

Linda M.: MMM.

What about?

ABOUT CORN. ALL THAT CORN GREW IN A FIELD.

Anything else?

THERE WAS A ROOSTER.

What did he do?

HE MIGHT HAVE EATEN THE CORN.

How come?

ROOSTERS EAT CORN.

What about the sun?

THE SUN GOES UP HERE BECAUSE IT SHINES FROM ABOVE.
[Moves the sun picture card]

Does the sun have anything to do with helping the rooster to grow?

I DON'T THINK SO.

Nothing?

[Shakes head]

What about the girl?

NO, SHE JUST EATS THE ROOSTER.

Is that what she's doing here?

OH, I GET IT. THAT'S FRIED CHICKEN.

Does that make your story different?

I DON'T THINK SO. I HATE CHICKEN!

Linda gave no evidence throughout the interview that she recognized a conceptual relationship among the pictures. Her total performance was rated as category 8 , and her cognitive map was drawn omitting the concept of a food chain. Perhaps this is a concept which she understands and uses, but sufficient verbal evidence was not given during the interview. It should be emphasized here that cognitive maps represent concepts which the interviewer has reason to believe are understood by the child; the fact that concepts are not "filled in" cannot always be interpreted as an indication that the child does not use these concepts. Often the questioning has not provided the child an opportunity to demonstrate a concept.

Because procedures for expressing cognitive map results have not yet been developed in either concise form, or forms applicable to group tendencies the remainder of the *results* of this study will be reported as individualized dialogues and cognitive maps. The three following excerpts from interviews were taken as evidence that the child was using a concept of *molecule, change-energy relationship, and potential energy*, respectively:

Interviewer: We cannot see into this bottle because it is dark colored, but can you tell me what's inside?

Lori S.: NO, BECAUSE IT'S . . . OH, YUK!! IT MUST BE NAIL POLISH.

How did you know that it was nail polish?

WHEW! CAUSE I SMELLED IT.

And the smell told you that it was nail polish?

YES.

Well, the one thing that I don't quite understand is how you could smell it when it was really inside the bottle?

OH, THAT'S BECAUSE THE AIR CAME OUT OF THE JAR INTO THE ROOM AND WE COULD SMELL IT.

Smell what?

THE NAIL POLISH. NO, IT'S NAIL POLISH REMOVER.

And is that what you smelled? Or was it the air?

NO, NOT THE AIR. SEE THE AIR IS IN THE JAR TOO, BUT THE NAIL POLISH REMOVER MIXES WITH IT AND THEY KIND OF COME OUT TOGETHER. . .

Do they ever . . .

AND SEE THE POLISH STUFF IN THE JAR IS MADE UP OF . . . MADE UP OF PARTS. THESE PARTS MIX WITH THE AIR PARTS.

Air parts?

YES. MOLECULES.

What?

I THINK THEY'RE MOLECULES. YOU SEE MOLECULES OF AIR ARE IN THERE AND SO ARE THE OTHERS. WHEN YOU OPEN THAT JAR THEY COME OUT AND GO EVERYWHERE. ALMOST EVERYWHERE. THAT'S THE WAY SMELLY THINGS WORK.

Okay. I have a picture here. Could you use a crayon to show me how smells work?

WHAT? OH, WAIT A MINUTE. [Draws a dot diagram]

Interviewer: Do you remember this thing? [A multiple battery board with a light bulb and small motor]

Laki K.: I SAW IT IN THE SCIENCE BOOTH, BUT I DON'T REMEMBER HOW TO DO IT.

Put the red plug in the green hole.

NOW I REMEMBER. THAT BATTERY MAKES THE LIGHT GO ON.

What if you put another battery on the board?

THE LIGHT WOULD GO ON MORE.

Try it.

THERE IT GOES MORE. BRIGHTER.

Why?

BECAUSE THE BATTERIES, THEY'RE THE ENERGY, AND IF YOU HAVE MORE IT WILL BE BRIGHTER. I MEAN MORE BATTERIES IT WILL BE BRIGHTER. WANT TO SEE? IF I PUT THESE ONES UP HERE THEN IT WILL BE BRIGHTER. SEE.

Okay, but there's still one thing I don't understand. Why should more batteries make more light? Could you tell me that part again?

[Sighs] BATTERIES HAVE ENERGY. ENERGY MAKES THINGS GO. SO IF YOU HAVE MORE ENERGY THINGS GO MORE. OR SOME OF THEM GO BRIGHTER.

I understand. What about the motor? Is what you just told me true for the motor?

IT SHOULD BE. DO YOU WANT ME TO TRY IT?

Yuh.

HERE? [Points to the socket on the motor circuit]

I think so,

HMM? IT DOESN'T GO WITH ONE BATTERY. WANT ME TO TRY TWO?

Do you think that will make it go?

I HOPE SO. [Adds a second battery] THERE IT GOES. OH, NO! IT STOPPED. LET ME PUT ANOTHER. AH, NO, IT'S REALLY GOING. THAT'S WHAT I TOLD YOU, RIGHT?

What's that?

MORE BATTERIES AND THINGS GO BETTER. THAT'S BECAUSE THE BATTERIES ARE REALLY THE ENERGY AND IT'S THE ENERGY THAT MAKES THEM GO.

Why didn't the motor go with one then? It had energy.

CAUSE THE MOTOR TAKES MORE THAN THE LIGHT. SOME THINGS GOT TO HAVE A LOT TO START.

Interviewer: I've got two pictures here of bows and arrows.
Could you tell me any story about *energy*
using these?

Christine B.: THIS FIRST ONE IS USING ENERGY. YOU CAN SEE THAT,
THE ARROW IS FLYING OUT FROM THE BOW. WHEN THINGS
ARE MOVING LIKE THAT THEY ARE - THAT IS WHEN THERE IS
ENERGY. THERE HAD TO BE ENERGY FOR THE ARROW TO GO.

Where did it come from?

THE PERSON THAT PULLED THE STRING BACK. THE STRING ON
THE BOW. WHEN THEY PULL IT BACK THERE'S ENERGY AND
WHEN THEY LET IT GO, WELL, THERE IT STILL IS, ONLY NOW
IT'S GOING.

How about the other picture?

THAT'S THE SAME ONLY EARLIER. IN THAT ONE HE'S
GETTING READY TO FIRE THE ARROW.

Any energy?

SURE THERE'S ENERGY. BUT IT'S JUST READY. YOU CAN'T
SEE ANYTHING FLYING YET. THAT COMES IN THE OTHER
PICTURE.

I see. Would you say that these two pictures are
the same? Different?

THE SAME.

This type of interview, taken as evidence of scientific concepts, led
to the construction of the 285 cognitive maps. Examples of the form in which
these maps were recorded are shown in Figures 8-10.

All rating categories in Table 1 were determined directly from the
audio-tapes or from transcripts of the audio-tapes.. A second effort at
assigning each interview to a rating category was made from the cognitive
maps without reference to the original recording. As both procedures were
carried out by the same investigator the second procedure was clearly not
intended to produce a more accurate indicator of the children's conceptual
development, rather the comparison was made in order to produce an index by
which the investigator could assess the feasibility of totally replacing

Figure 8. A sample cognitive map based upon interview #2.
This child was rated as a modeler.

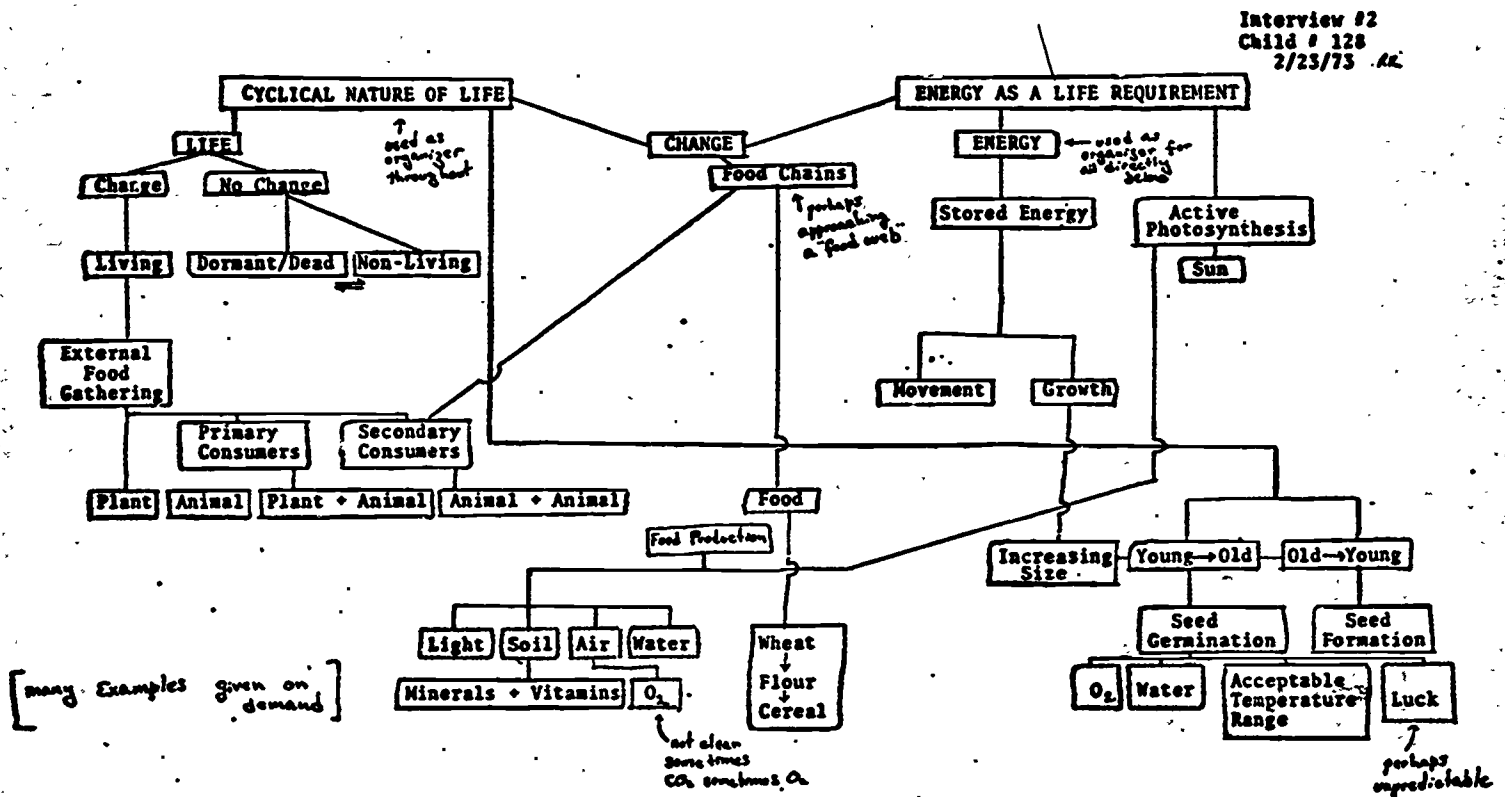


Figure 9. A sample cognitive map based upon interview #3.
This child was rated as a transitional modeler.

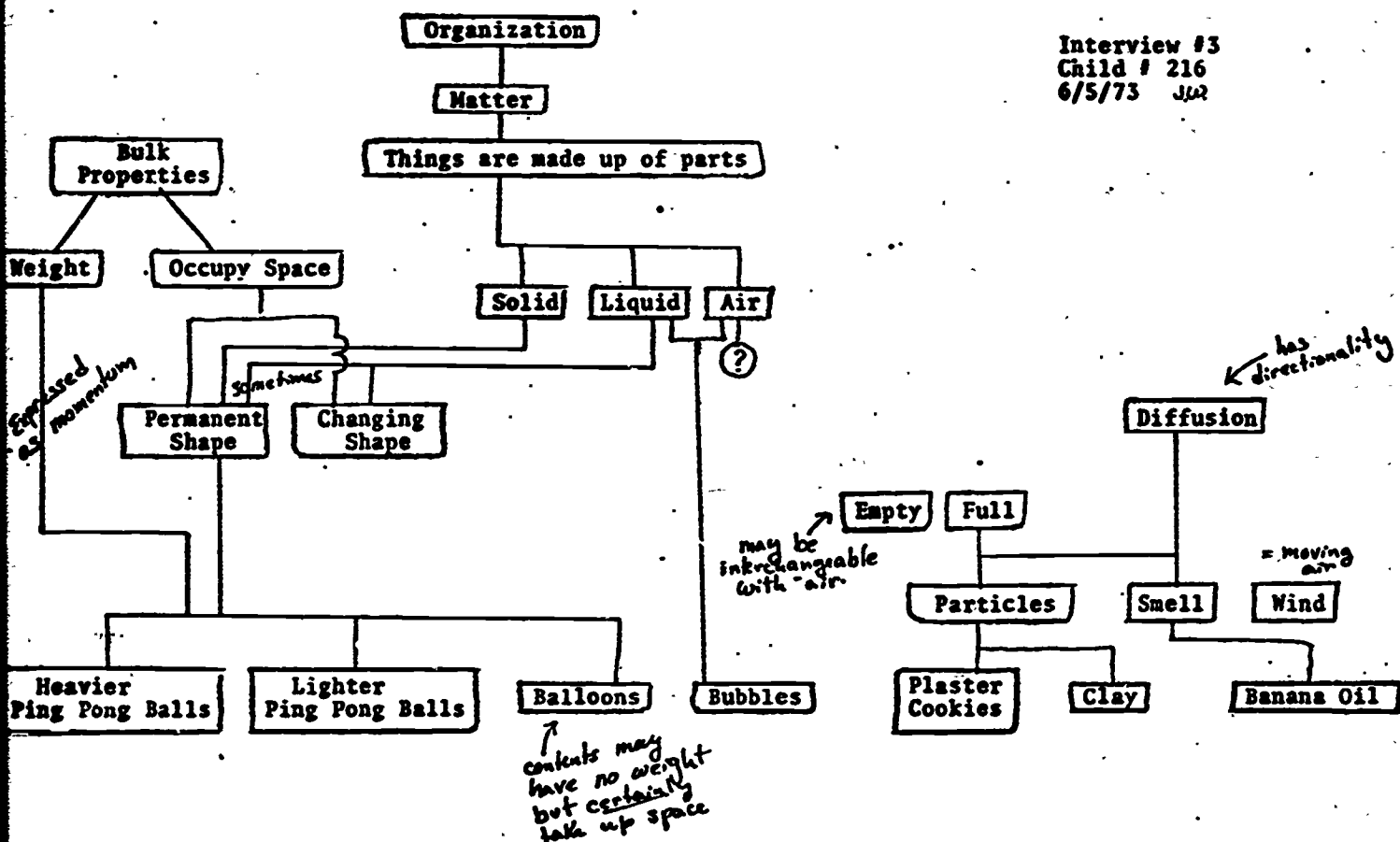
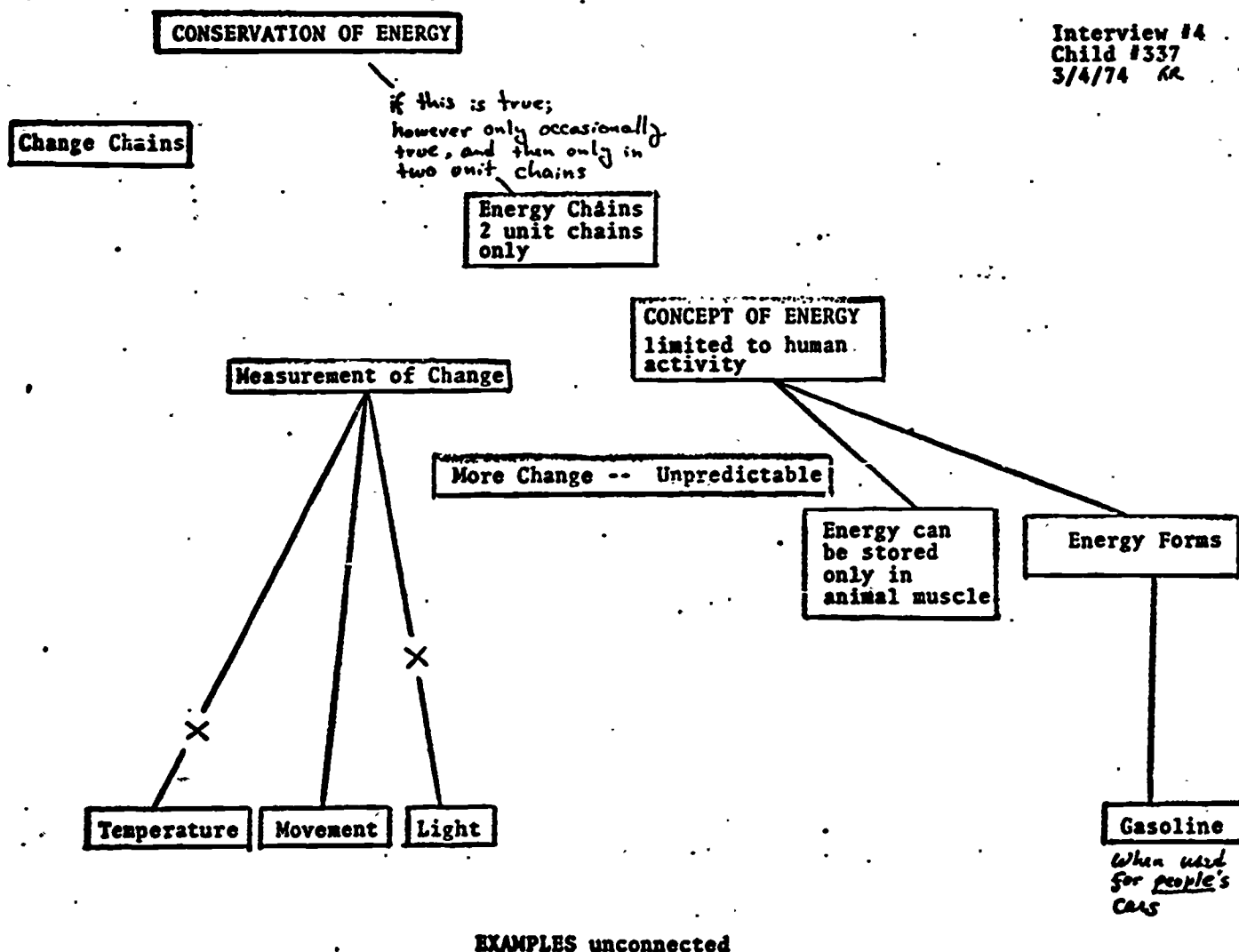


Figure 10. A sample cognitive map based upon interview #4.
This child was rated as a non-modeler.



the rating category *via* interview by a cognitive mapping technique in future studies.

Some categories from Figure 7 are not applicable to rating from maps. For example, the temporal reference "learns model during the course of the interview" cannot be extracted from a map. Therefore a comparison of ratings, using the two different records (tape and map), was limited to the three macro rating categories: *Modeler*, *Transitional Modeler* and *Non-Modeler*. Ordinal numerical values of 1, 2 and 3 were assigned to these categories respectively, and Pearson product-moment correlation coefficients were calculated for the relationship between tape-originated categories and map-originated categories. The comparison is as follows:

Table 4. Comparison of macro rating categories made from the two data sources - cassette tape-recordings, and cognitive maps - with the tape-map correlation coefficient for each interview.

T A P E	M A P								
	MODEL			TRANSITIONAL			NON-MODELER		
	MODEL			TRANSITIONAL			NON-MODELER		
	MODEL			TRANSITIONAL			NON-MODELER		
MODEL	54	2	1	37	5	1	38	4	1
TRANSITIONAL	7	14	5	12	19	1	1	25	4
NON-MODELER	2	0	10	1	2	17	2	0	20
Interview #2			Interview #3			Interview #4			
$r_{xy} = .786$			$r_{xy} = .763$			$r_{xy} = .833$			

CONCLUSIONS.

We believe that ATESP children are learning important science concepts. Models for meaningfully viewing the natural world are clearly being learned by over one half of the children studied, and another third gave some evidence of using these models. We would, of course, like to see a greater percentage of these children applying the hierarchically ordered concepts that were made available via A-T lessons, yet we recognize that the total cumulative time spent doing ATESP lessons by any one child may represent no more than thirteen and one-half hours of his/her first, second, and third grade lifetime. The fact that we find *any* significant difference in ordinal ratings between these children and a control group is encouraging. It is, however, of concern to us that we have been able to label this control group as "uninstructed". We saw no form of organized science instruction in the many elementary classrooms visited.

The fact that only one-fourth of the uninstructed children gave evidence of using models is alarming when viewed in light of Ausubel's subsumption theory of learning. We have demonstrated that with a small instructional time investment twice as many children will act as modelers. If these models serve as a cognitive organization within which new information can be added meaningfully, it is important that children be aided in the development and use of such models early in their school careers.

On the other hand, we are comforted by the observation that as many as one-fourth of these uninstructed children are forming acceptable and stable scientific models in spite of the *smorgasbord* type of science instruction that they are receiving. With almost one-half of the uninstructed children using a continuity of life model we are led to believe that the relatively abundant information regarding life sciences is being incorporated meaningfully into cognitive structure.

We are further encouraged that the analysis system presently being employed - cognitive mapping - is providing a penetrating and sufficiently reliable description of elementary school children's concepts of natural phenomena. We advocate the use of these maps as a reporting

system of children's progress in elementary school science, and we hope that the science education research community will add to the pool of such descriptions.

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APPENDIX A

Audio-tutorial Elementary Science Project

Level 1	Lesson <u>Number</u>	Lesson <u>Title</u>
	1	Classification of Objects By Their Size, Shape and Weight
	2	Classification of Batteries: Some Batteries Can Make Bulbs Light and Others Cannot
	3	Batteries Are a Source of Electric Energy: Electric Energy Can Cause A Bulb To Change
	4	Electric Energy Is Involved In Many Kinds Of Changes
	5	Whenever You Notice A Change You Know That Energy Is Involved
	6	Differing Amounts Of Change Occur When More Energy Or Less Energy Is Involved
	7	Energy Can Be Stored and Involved In Future Changes
	8	People Use Energy and Change Themselves and Other Things
		I N T E R V I E W O N E
	9	There Are Some Ways In Which All Animals Are Alike
	10	Moving and Growing Are Changes: All Animals Use Energy From Food To Change
	11	Different Animals Eat Different Kinds Of Food
	12	Growing Plants Need Air, Water and Light
	13	Living Seeds Change In Certain Ways
	14	Growing Is A Kind Of Change In Plants And Animals
	15	A Comparison Of Plants And Animals
	16	Nothing Changes By Itself
		I N T E R V I E W T W O
	17	Air Is Real; Air Causes Changes
	18	Some Distinctive Features Of Solid Things, Liquid Things, And Air
	19	Things Are Made Of Parts

- 20 All Solid Things Can Be Thought Of As Being Made Of Little Parts. These Little Parts Can Be Called Molecules
- 21 All Liquid Things and Air Can Also Be Thought Of As Being Made Of Little Parts Called Molecules
- 22 Wind And Smells Demonstrate The Movement Of The Molecules Of Air
- 23 Air Molecules Are Constantly Moving Around
- 24 The Molecules Of A Solid Do Not Move Around Freely, While The Molecules Of A Liquid Move More Freely, And The Molecules Of Air Move Most Freely

I N T E R V I E W T H R E E

- *25 When A Solid Thing Becomes Warmer Its Molecules Move Around More And More And The Solid Thing Becomes More Like A Liquid
- *26 Big Changes Are The Result Of Many Smaller Changes
- *27 When You Notice A Solid Changing And Becoming A Liquid You Know That The Molecules Are Changing And That Energy Is Involved
- *28 Things Do Not Change By Themselves. When You Notice A Change You Can Find Many Things Happening
- *29 Hot Things And Cold Things
- *30 How A Hot Thing Can Change The Temperature Of A Cold Thing

Level 2 Lesson Number Lesson Title

- 1 Classification Of Materials
- 2 Changes And Things That Cause Them
- 3 Energy Is Involved In All Changes
- 4 Energy Is Involved In Changes That Can Be Measured

I N T E R V I E W F O U R

- 5 Solids And Liquids Are Made Up Of Molecules
- 6 Air Is Made Up Of Molecules
- 7 Motion Of Molecules In The Air May Bring About Interactions Like Pushing Of Objects Or Like Spreading Of Smells

I N T E R V I E W F I V E

- 8 Forces: Some Interactions Result In Movement

- 9 In Everyday Experience Force Encounters Opposing Forces
10 Balance And Imbalance Of Opposing Forces

INTERVIEW SIX

- 11 Evidence For The Spherical Shape Of The Earth
12 Lands And Oceans Together Constitute The Earth's Spherical Surface. Travelling From Place To Place Is Travelling On A Spherical Surface
13 Space Surrounds Earth. The Earth Is Only One Reference Point In Space. The Moon Might Be Another Reference Point In Space
14 The Earth Attracts All Objects Toward Its Center And This Causes Up-Down Directions Around The Earth To Be Radial
15
16

INTERVIEW SEVEN

- *17 Introduction To The Life Stateion. Plants And Animals
*18 Animals And Plants Need Water And Air And Energy To Stay Alive. We Use Energy All The Time
*19 Plants Do Not Change By Themselves; They Need Energy To Change. Little Plants Use Energy That Is Stored In The Seed
*20 A Life Cycle: Adult Green Plants Produce Seeds, The Seeds Can Grow Into More Plants Like The Adult, Adn Can Produce More Seeds
*21 All Animals Must Get Food, And Water, And Air To Stay Alive. Animals Have Special Parts To Help Them Get Food And Water And Air
*22 It Takes A Lot Of Food Energy To Change From A Baby To An Adult. All Plants And Animals Change In Going From Young Plants And Animals To Adult Plants And Animals, And Then They Can Have More Young Plants And Animals.
*23 Small Populations Of Adults Produce Relatively Small Amounts Of Eggs or Seeds, Larger Populations Of Adults Tend To Produce Larger Amounts of Eggs Or Seeds
*24 We Must Eat Food To Get Energy To Grow And Change. Animal Populations In The Food Chain Depend Upon Other Populations
*25 A Food Chain Starts With A Population Of Plants, Then An Animal Population That Eats The Plants, And Then Another Animal Population That Eats The First Animal Population

INTERVIEW EIGHT

* Lessons not presently in use

APPENDIX B

Interview #4

ENERGY TRANSFORMATIONS

*0. Picture of Two Bean Plants (from Lesson II-1)

0-1 DO YOU REMEMBER THESE?

TELL ME WHAT HAPPENED WITH THEM.

WHAT DO PLANTS NEED IN ORDER TO GROW?

0-2 THE PERSON WHO DREW THESE PICTURES TOLD ME THAT PLANTS NEED _____, _____, _____, IN ORDER TO GROW. HE ALSO SAID THAT THEY NEED SOME FORM OF ENERGY, EITHER FROM THE SUN, OR IF THEY ARE KEPT IN THE DARK, THEN FROM THE STORED FOOD ENERGY IN THE SEED.

DOES THAT STORY MAKE SENSE TO YOU?

I'M GOING TO ASK YOU SOME OTHER QUESTIONS ABOUT ENERGY.

I. Picture of Ice Cube Melting

1-1 WHAT'S THIS? WHAT'S HAPPENING? WHY?

1-2 DOES THIS PICTURE HAVE ANYTHING TO DO WITH ENERGY?
IN WHAT WAY?

II. Two Pictures of Cows (1 sitting, 1, running)

2-1 COULD YOU USE THESE TWO COW PICTURES TO TELL ANY KIND OF STORY ABOUT ENERGY?

WHAT WOULD YOU SAY?

2-2 IS COW A A GOOD ONE TO USE IN AN ENERGY STORY?

IS COW B A GOOD ONE TO USE IN AN ENERGY STORY?

III. Two Bow + Arrow Pictures

3-1 DO THESE BOW + ARROW PICTURES HAVE ANYTHING TO DO WITH ENERGY?

3-2 WHERE DOES THE ENERGY IN PICTURE A COME FROM?

WHERE DOES THE ENERGY IN PICTURE B COME FROM?

IV. Picture of a Pendulum, also a Pendulum

4-1 WHAT DOES THIS THING DO?

HOW DOES IT WORK? WHERE DOES THE ENERGY COME FROM?

4-2 IF I HOLD IT IN THIS POSITION, JUST LIKE IN THE PICTURE, WHAT WILL HAPPEN NEXT? WHY?

V. Alcohol Lamp

5-1 WOULD YOU PUT YOUR HAND OVER THIS LAMP?

WHAT HAPPENS? HOW COME?

5-2 WHAT DO YOU SUPPOSE IS INSIDE THE LAMP?

5-3 DOES THIS THING HAVE ANYTHING TO DO WITH ENERGY?

IN WHAT WAY?

****VI. Nine Plastic Bottles: Seeds, Wheaties, Light Bulb, Battery,
Water, Gasoline, Sawdust, Dead Flies, Gravel**

**6-1 COULD YOU CHOOSE THE BOTTLES THAT YOU THINK MIGHT
CONTAIN ENERGY?**

6-2 WHAT MAKES YOU THINK THESE CONTAIN ENERGY?

6-3 WHAT MAKES YOU THINK THESE DO NOT CONTAIN ENERGY?

VIII. Tuning Fork

7-1 COULD YOU HIT THIS THING?

WHAT HAPPENS? WHY?

7-2 DOES THIS HAVE ANYTHING TO DO WITH ENERGY?

**SOME PEOPLE SAY THAT SOUND IS A FORM OF ENERGY:
DOES THAT MAKE ANY SENSE TO YOU?**

VIII. Radiometer, Rheostat, and Table Lamp

8-1 DID YOU EVER SEE ONE OF THESE?

WHAT DO YOU THINK IT CAN DO?

8-2 WATCH. [Switch on at 90 volts]

WHAT HAPPENS? WHY? WHAT MAKES IT SPIN AROUND?

WHAT DOES THIS HAVE TO DO WITH ENERGY?

**8-3 WILL IT MAKE ANY DIFFERENCE IF I MAKE THE LIGHT
BRIGHTER? WHAT HAPPENS? WHY?**

IX. Multiple Battery Board (from Lesson I-4)

9-1 DO YOU REMEMBER THIS THING?

WHAT CAN YOU DO WITH IT?

SHOW ME WHAT HAPPENS WHEN YOU PUT THE RED PLUG IN THE GREEN HOLE.

9-2 WHY DOES THE BULB LIGHT UP?

9-3 WHAT HAPPENS IF YOU PUT SOME MORE BATTERIES ON?

WHY SHOULD THAT MAKE ANY DIFFERENCE?

HOW ABOUT IF YOU ADD THIS LITTLE ONE? [C cell]

9-4 HOW ABOUT THE MOTOR? CAN YOU MAKE THAT GO?

WHY SHOULD IT TAKE TWO OR THREE BATTERIES WHEN THE LIGHT WENT WITH ONE?

9-6 COULD YOU EXPLAIN THIS WHOLE THING TO ME AGAIN FROM THE BEGINNING?

X. Seven Cards with Arrows Representing Energy

10-1 HERE ARE SOME CARDS WITH ARROWS AND THIS CARD SHOWS THAT AN ARROW IS GOING TO STAND FOR ENERGY.

DOES THAT MAKE SENSE TO YOU?

10-2 WHICH CARDS WOULD BE THE BEST ONE TO SHOW ENERGY IN THIS ROOM?

XI. YOU'VE TOLD ME A LOT ABOUT ENERGY, BUT WHAT WOULD YOU DO IF YOU HAD TO EXPLAIN ENERGY TO SOMEONE WHO DIDN'T KNOW ANYTHING ABOUT IT?

WHAT WOULD YOU TELL THEM?

WHAT IS ENERGY?

COULD YOU SHOW THEM ANYTHING THAT WOULD HELP?

Questions are flexible; they appear here in the forms most often used during the 1973-1974 school year.

* This is not intended to be a question. It is intended to set the tone of the interview. "We will be talking about ways of thinking about energy".

**This question should be asked at that point in the interview when the child has already begun to reveal his definition of energy. If he expands his definition during this question, previous questions may be reasked.

Interview #4 - Alternate

ENERGY TRANSFORMATIONS

0. Radiometer/Rheostat/Table Lamp

[See Interview 4, Question VIII; also note on Interview 4, Question 0.]

I. Multiple Battery Board (from Lesson I-4)

[See Interview 4, Question IX.]

II. Bulb/Nichrome Wire/Motor Board

2-1 HERE'S ANOTHER TOY . WHAT HAPPENS WHEN I PLUG THE WIRE INTO HERE?

WHY?

2-2 WHEN I PLUG IT INTO THE MOTOR?

WHY?

2-3 WHEN I PLUG IT INTO THE BULB?

WHY?

2-4 HOW CAN THAT SAME BATTERY DO SO MANY DIFFERENT THINGS?

III. Picture of an Ice Cube Melting

[See Interview 4, Question I.]

IV. Nine Plastic Bottles:

[See Interview 4, Question VI, including note.]

V. Two Pictures: Boy Climbing a Slide, Boy Sliding Down a Slide

5-1 COULD YOU USE THESE PICTURES TO TELL A STORY ABOUT ENERGY? WHAT WOULD YOU SAY?

5-2 WHAT DO YOU SUPPOSE THE ARROWS MEAN IN THE PICTURES?

VI. Inclined Plane Toy (from Lesson II-2)

6-1 DOES THIS BALL [at the bottom of the ramp] HAVE ENERGY?

6-2 HOW ABOUT IF I PUT IT HERE, AT THE TOP OF THE RAMP?

WHERE DID THE ENERGY COME FROM?

VII Four Pictures: Sun, Corn, Chickens, Boy Eating Chicken

[See Interview 2, Question VI.]

VIII. [See Interview 4, Question XI.]