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ABSTRACT

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LEARNING RESEARCH AND DEVELOPMENT CENTER

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2

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Abstract

This paper describes and demonstrates an analysis process which uses hierarchy construction procedures. These procedures are used to analyze the Individualized Science program. In the hierarchy construction process, the instructional materials are the input data. Separate concept, content, and skill analyses are performed across all levels of the course materials and hierarchies of instructional objectives are structured. The final product is a blueprint of the curriculum revealing the underlying design model. The developers' claims are examined in light of the evidence revealed through the analysis procedures.

A CURRICULUM ANALYSIS OF INDIVIDUALIZED SCIENCE

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Introduction

One important aspect of a curriculum evaluation is a careful, systematic analysis of the curriculum materials. Curriculum analysis is of value for curriculum evaluation because it facilitates comprehension of a curriculum's goals, structure, and instructional strategies. It can help to answer certain key questions that evaluators normally ask about a curriculum and, in addition, can bring to light some questions about the curriculum that evaluators ought to ask. This paper describes and demonstrates such an evaluation of the Individualized Science (IS) program (Champagne & Klopfer, 1974) developed at the Learning Research and Development Center of the University of Pittsburgh.

Scriven (1967) has termed analysis/evaluation of curriculum materials "intrinsic evaluation" and has pointed out that it is often not done because of the difficulty of the process. Although various procedures for carrying out curriculum analysis (intrinsic evaluation) have been proposed (e.g., Eash, 1974; Morrisett, Stevens, & Woodley, 1969; Tyler, Klein, & Michael, 1971), none of these procedures is fully adequate for analyzing the sophisticated curricula that contemporary instructional technology is capable of producing. Many curricula today are highly complex, multifaceted, carefully integrated instructional packages. In order to fully understand how these complex packages try to achieve their goals, curriculum analysis is essential. The hierarchy construction process (Gow, Note 1) demonstrated in the present study of IS is useful for this purpose.

In the hierarchy construction process, the instructional materials of the curriculum are the input data for analysis. Hierarchies of curriculum objectives are constructed to show how the materials build instruction toward attainment of the curriculum's goals. The completed hierarchies serve as evidence to support the conclusions of the analysis. In addition, the process of constructing hierarchies often reveals features of the curriculum that are otherwise not readily apparent. If a curriculum does or does not attain its goals, how it succeeded or how it failed are equally important questions for evaluators. The hierarchy construction process is a new tool that the curriculum evaluator can use in seeking answers to these questions.

Constructing hierarchies of instructional objectives is not new. Curriculum designers often construct such hierarchies (e.g., Gagné, 1968; Resnick, 1973, 1976).[1] The process is essentially the same for design and analysis. In the design process, an instructional model may lead to the structuring of instructional materials that enable the student to attain the objectives. In the analysis process, the instructional materials are analyzed to identify the specified or implied objectives, the inferred instructional hierarchies are constructed, and the instructional model is reconstructed. The two processes may be diagrammed as follows:

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[1] Not all hierarchies are constructed by the same rules. For example, a hierarchy generated logically from an analysis of a concept according to the structure of the subject matter discipline will differ from a hierarchy generated from an analysis of that concept based on psychological principles of concept development. Gagné's hierarchies are essentially psychological. The hierarchy construction process used in this study attends not only to psychological sequences, but to the logical structures of the subject matter discipline and pedagogical sequences as well.

DESIGN: Instructional Model → Goals (Objectives) → Hierarchies → Instructional Materials

ANALYSIS: Instructional Materials → Goals (Objectives) → Hierarchies → Instructional Model

Sometimes instructional objectives and hierarchies have not been specified in the original design of a curriculum. However, whether they were specified or not, objectives and some structural organization exist in any formal instructional situation, and these are what the analysis process seeks to uncover.

The hierarchy construction process used in this study attends to conceptual structure of the subject matter, skill level, subject matter content, and affective and cognitive goals. The resulting hierarchies display how the curriculum attempts to attain its goals and show the interrelationships among the curriculum's goals and objectives. They help the analyst to pinpoint structural strengths or weaknesses and also gaps or inconsistencies, if any exist. A by-product of the careful analysis of curriculum materials is the identification of instructional strategies used in the materials and of essential elements of the curriculum's management system.[2] Regularities in the use of strategies and other patterns of design characteristics make explicit the instructional model on which the curriculum is based. In addition, the curriculum analysis process may raise significant questions that can be addressed by means of other forms of curriculum evaluation.

The Hierarchy Construction Process

As already mentioned, hierarchy construction in curriculum analysis uses the instructional materials of the curriculum as input data for

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[2] The management system is that part of the curriculum that defines how an individual student's progress through the curriculum is managed.

the analysis. These data are supplemented by training materials prepared for teachers and by the curriculum developer's own descriptions of the materials, when they exist. The physical product of the analysis is a series of hierarchy charts that present an organized, comprehensive view of the curriculum. In this section, the kinds of materials and some general considerations in the hierarchy construction process are discussed.

The primary materials that are used in the analysis are student instructional materials, including both printed and other media materials. For a curriculum that does not have explicitly stated objectives, the student materials are the main source of information about what content, concepts, and skills the curriculum is seeking to teach. In this context, content is viewed as information, events, and data at the knowledge level of the <u>Taxonomy of Educational Objectives, Handbook I: Cognitive Domain</u> (Bloom, 1956). Concepts are those salient ideas associated with a particular discipline from which the structure of the discipline is formed.[3] Skills include not only intellectual skills, which are called "behaviors" in the Bloom <u>Taxonomy</u>, but also any manual skills and learning management skills that are part of the curriculum's instruction. The presentation of content and the development of concepts and skills that constitute the student instructional materials of a curriculum become the source of information about the curriculum's content, concept, and skill objectives in the absence of explicitly stated objectives.

To supplement the examination of the student materials, the teacher's manuals or guides are examined. These usually are more or less explicit about the content, concepts, and skills the curriculum

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[3] The concepts of a discipline involve both knowledge and process. Those concepts of the discipline that the curriculum seeks to teach may be identified by performing a concept analysis (see Gow, Note 2).

seeks to teach, even when specific objectives are not stated. The teacher's manuals also are a good source of information about the attitudes and values the curriculum is seeking to promote. Some curriculum management system artifacts which should not be overlooked are the student record forms, teacher planning forms, activity outlines, tests, and answer keys. These components of the management system may support or may fail to support the curriculum's expressed or implied objectives.

For a curriculum that has explicitly stated objectives, examination of the student materials is necessary to flesh out the curriculum model in terms of the instructional strategies that are utilized and to reveal implied objectives. Some rich curricula probably teach more than they test for or express as objectives. Consequently, if a skill is taught and practiced, it may be assumed that skill is an objective of the curriculum, whether or not it has been expressed as being one. Similarly, if a concept is introduced with multiple examples, it may be assumed that the concept is an objective. On the other hand, content, facts, and isolated examples of concepts may well not be objectives to be learned if they are not explicitly listed as such. The curriculum's objectives usually are listed in the teacher's manuals, and such lists may be used directly as input for the curriculum analysis. In addition, matching the objectives in the teacher's manuals with the student materials will reveal implied objectives that also must be included in the hierarchy constructed.

Other important sources of input data for the analysis are the rationales and occasional reflections written by the curriculum developer(s). These may be found in professional journal articles describing the curriculum, in advertising materials, or in teacher's manuals. Usually, rationales embody the curriculum goals and describe the philosophy of the developer. These are useful clues to the curriculum's theoretical underpinnings.

Process Individualized Curriculum Model

The hierarchy construction process employs the Process Individualized Curriculum (PIC) model (see Gow, Note 2). The procedures of the PIC model require prestructuring concepts, content, and skills separately before merging the three structures into one hierarchy. In constructing this hierarchy, the logical order of content and concepts, the sequence of elements of the subject matter structure (concepts, principles, generalizations, and constructs), and the taxonomy levels of skills or attitudes are considered.[4]

The content structure of most curricula is the easiest element to identify. However, for a curriculum that explicitly emphasizes concepts, the concept structure is more readily identified. The specific content instances may not be crucial for a concept-structured curriculum. What _is_ important is the range of these instances and the number of relevant and irrelevant attributes (Klausmeier & Hooper, 1974). For any curriculum, the concept structure should be identified and the content instances should be charted to display their function in concept acquisition. The evaluator who uses the hierarchy construction process can be confident that the hierarchies produced reflect the structure of the actual curriculum, whether or not it matches the designer's intent. The curriculum materials reflect the decision made by the designer in selecting from among alternative structures, and they are the evidence that limits the range of possible interpretations when an existing curriculum is analyzed.

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[4] The use of the PIC model to construct hierarchies for curriculum analysis and evaluation is especially appropriate for individualized curricula. However, any formal instruction may be expected to have objectives build on one another as instruction proceeds. Both the objectives and the structure may be implicit rather than explicit, but they exist and can be charted.

Using the PIC model for analysis of a curriculum involves a number of steps.

First, content, concept, and skill analyses are carried out and then combined to structure an instructional hierarchy. Some curricula may specify objectives and present already structured hierarchies. These are matched to materials, observing any discrepancies that exist between specified objectives and the materials designed to teach those objectives. For curricula that do not have specified objectives and/or hierarchies, the materials are examined and the objectives inferred and structured. After this initial analysis is completed, the broad inclusive concepts of the discipline are organized according to levels (grades or units in a single curriculum) and the hierarchical sequence of the subconcepts, principles, generalizations, and constructs determined. The content instances are then analyzed and placed under the appropriate level of the concepts of which they are examples. Finally, the skills are merged with concept and content instances to define, in behavioral terms, the implied objectives.

The second step of the process is the identification of instructional strategies. The identification of instructional strategies can be simply an inventory to define the instructional model more clearly. In this step, strategies which might be particularly appropriate for certain kinds of instruction and have been neglected (e.g., modeling for psychomotor skills, advance organizers for learning from reading, etc.) are identified. Special attention is given to concept acquisition strategies. The kind and range of examples of each concept (content instances) and their relevant and irrelevant attributes are noted. Failure to learn a concept may result from a defect in the instances encountered in instruction. The range of content instances is readily apparent from observation of the hierarchy.

Third, the instructional model is described. Specified or inferred goals and objectives are identified and their interrelationships determined.

This description is based on the information obtained from the initial analysis of the content, concepts, and skills of the curriculum. Then, the principles of instruction used in the curriculum materials, management system, and teacher training materials are described based on information obtained when the instructional strategies were identified.

The fourth step in the PIC model for curriculum analysis involves the identification of components of the curriculum that seem to suggest fertile fields for further investigation. For examples of such questions raised in the analysis of IS, see page 32.

Hierarchy Construction

In constructing the hierarchies, separate charts are built for the cognitive and affective domains and for other elements of the curriculum that represent separate expressed or implied goals. The levels at which objectives are charted depend upon the instructional sequence (if one is prescribed), the taxonomy level, the level of abstractness, and the concept level.

The elements of a typical hierarchy are identified in Figure 1. The lines that connect objectives vertically represent dependency relationships. Horizontal lines connect separate elements that lead and contribute to a common objective, but that are not dependent on each other. The branches of a hierarchy generally represent different phenomena towards which the student's behavior is directed. They also may represent separate content of particular elements of a goal that make distinctive demands upon the student. (For examples, see Appendix A, Exhibits 1 and 2, pages 42-43.) The process of analysis requires that the analyst identify and categorize distinctive features of such demands.

In preparing hierarchies analyzing curricula with specified goals and objectives, it is noted when the wording of expressed objectives is

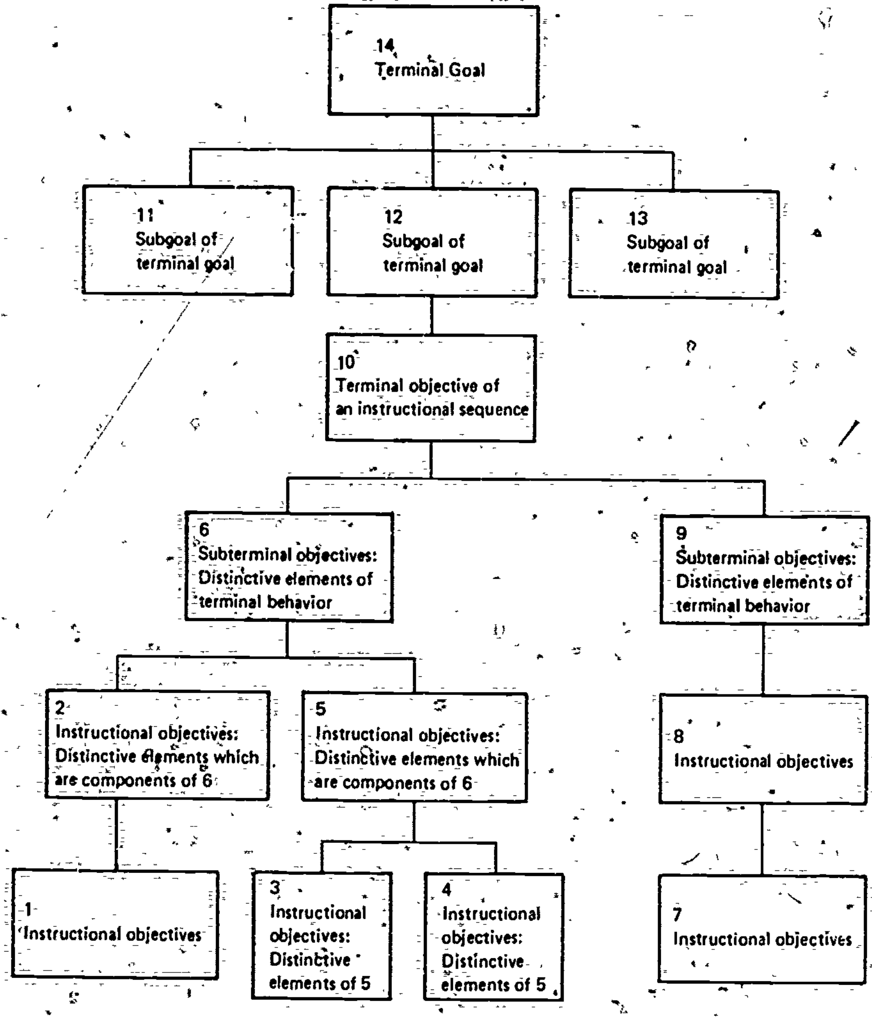

Figure 1. Elements of a hierarchy.

changed by the analyst or when two or more objectives are combined. It is also noted if rewording changes the meaning or emphasis of an objective, if an objective is added to represent a learning experience for which there is no expressed objective, or if an objective is added to represent an untaught objective prerequisite to a specified objective. For curricula that do not have expressed objectives, it is simpler to note those goals and objectives stated by the developer instead of those inferred or added. In either case, it is important that a clear differentiation be made between the developer's words and expressed intent and the analyst's words and inferences.

Analysis of Individualized Science

Individualized Science (IS) is a comprehensive elementary school science program designed for students in grades 1 through 8. The IS program has been described by its developers as "a science curriculum closely integrated with an individualized learning management system" (Champagne & Klopfer, Note 3, p. 2). The overall plan for IS includes seven levels of instructional material, each level providing approximately one school year's work in science. Only the first five levels of IS, Levels A through E, are considered in the present analysis.

IS is a very complex curriculum, offering many different kinds of learning experiences and a variety of paths to mastery of its goals. Hierarchies were not constructed during the development of the curriculum but the developers, Drs. Audrey Champagne and Leopold Klopfer, used two organizational schemas to identify affective and cognitive levels and structure the phenomena and content of science. Summary charts of these two schemas are included in Appendix A, Exhibits 1 and 2, pages 42-43. The affective schema makes use of the categories of student behavior from the Taxonomy of Educational Objectives, Handbook II: Affective Domain (Krathwohl, Bloom, & Masia, 1964) and applies these to the phenomena that are of interest to science education (see Klopfer, Note 4). The cognitive schema is based, in part, on Bloom's (1956) cognitive taxonomy, but this has been modified to be science-specific and expanded to include the processes of scientific inquiry (see Klopfer, 1971a, 1971b). The two schemas used in developing IS may be viewed as providing a structure for the science curriculum. This structure also provided one of the dimensions for the hierarchy construction process.

Among the IS curriculum materials examined in the analysis were: Individual Lessons (IL), Planning Booklets, Men and Ideas Filmstrips (M&I), Student Activities (SA), Miniature Explorations (MinEx), Invitations to Explore (ITE), Science Learning Games (SLG), Self-Initiated Independent Activities (SIIA), Directed Group Activities (DGA), Readings in Science (RIS), content guides and answer keys to the units, student science notebooks, and teacher's manuals. Examples of a learning resource chart, a content guide to units, an individual lesson booklet, and a MinEx are in Appendix A, pages 59-60. The teacher's manuals (excerpts in Appendix A, pages 61-64) were the most useful data source because they clearly set the tone of the program and contain a wealth of directions and suggestions for the teacher that could be examined for consistency with program goals. The writings of the developers were helpful in identifying their intentions, their claims for IS, and the kinds of formative evaluation questions they had sought to answer.

The goals of IS are stated as follows:

1. Scientific literacy goal: The student acquires a foundation of scientific literacy.
2. Student self-direction goal: The student views the learning process as primarily self-directed and self-initiated.
3. Student co-evaluation goal: The student plays a major role in evaluating the quality, extent, and rapidity of his learning.
4. Affective goal: The student displays informed attitudes toward his study of science, scientific inquiry, and the scientific enterprise.

5. Inquiry goal: The student becomes skillful in using the processes of scientific inquiry and is able to carry out inquiries. (Champagne & Klopfer, Note 3, pp. 7-8)

The interrelationships between the five goals and their subgoals were charted in an overview (see Appendix B, Chart 1, page 66). This chart is not hierarchical. Self-direction and co-evaluation goals appear at the bottom because they are the foundation for the kind of learning experience that is the heart of IS. Inquiry and attitudes towards inquiry follow because they encompass the processes and motivation necessary for, and involved in, the pursuit of the cognitive goals of the program. Finally, at the top are the scientific literacy and affective goals which build on self-direction, co-evaluation, inquiry processes, and attitudes toward inquiry. The arrows are intended to show that the relative progress along all five dimensions probably would vary from student to student and probably would not follow a step-by-step progression.

In many curricula, affective, inquiry, and self-management and evaluation goals often are less well defined, planned, and executed than are more traditional cognitive goals. For this reason, and because they gave promise of revealing some of the distinctive features of IS, the program's affective, inquiry, self-direction, and co-evaluation goals were analyzed before the scientific literacy goal.

Self-Direction and Co-Evaluation

The self-direction and the co-evaluation goals are charted as separate hierarchies (see Appendix B, Charts 2 and 3, pages 68-70). These goals were constructed with objectives from each of the five IS levels being analyzed and were charted consecutively from the bottom of the hierarchy to the top. Behaviors indicating progress are expressed in terms of tasks performed and are charted at the IS level at which they are introduced.

The four immediate subgoals to the self-direction goal were selected because they represent the four separate categories of tasks the student performs in pursuit of the terminal capability. Two of these are expressed by the developers: a long-range plan for the student's own learning, and selection and utilization of suitable instructional materials. Two were introduced here by the analyst because the demands of two different categories of capability were identified among the curriculum tasks. One type of task demands willingness to revise plans based on appropriate evidence; another type requires individual responsibility for use of human resources to attain instructional goals. This interjection of two subgoals is an example of how curriculum structure is made more evident through the analysis process.

The two immediate subgoals for co-evaluation summarize the two major categories of behavior involved: first, self-evaluation; second, discussion and co-evaluation with the teacher. In both of these categories, where analysis suggested addition of a subgoal immediately beneath the terminal goal and formation of a branch in the hierarchy, the objectives demand different types of behavior.

The student self-direction and co-evaluation goals require coordination of student planning sheets and booklets, teacher planning forms, teacher directions, outlines of unit activities grouped by topics, answer keys, etc. In the teacher's manuals, the teacher is reminded repeatedly to discuss the students' progress with them individually and to ask students to evaluate their performance and progress. In short, the two goals that "the student should view the learning process as primarily self-directed and self-initiated" and that "the student should play a major role in evaluating the quality, extent, and rapidity of his learning" are supported by all elements of the management system, and this support is reflected in the charted objectives.[5]

The concept of mastery with respect to the student self-direction and co-evaluation goals is relative, rather than absolute. The developers' publications (e.g., Klopfer, Note 5) give clues to the essential differences between the usual definition of mastery and the sense in which it is used for these goals. Self-direction is aimed at student "development into a competent and confident independent learner." Co-evaluation assumes "continually increasing responsibility" for judging how well the student performs in learning new information, ideas, and procedures. Levels of competency at any IS level will vary among individuals. This is an aspect of the curriculum that the hierarchy construction process has highlighted. Note, for example, the repeated use of the phrase, the student "is progressing" in the statement of IS competencies.[6] Each specified objective in all of these hierarchies represents a milestone, or behavioral evidence of progress towards the terminal goal.

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[5] In the case of IS, the specified objectives clue the curriculum analyst to the need to check for consistency. This might not be so in every curriculum. If IS did not have a specified self-management goal, explicitly stated, examination of the management system, student directions, and directions to teachers in the teacher's manuals would have shown self-management to be an implied goal and would have made clear the implied objectives, which could then be structured hierarchically.

[6] The terminology used by the analyst and the developers of IS to describe different levels of behavioral outcomes for a curriculum differ. IS developers use the terms goals, competencies, and objectives. Thus, they have analyzed each goal of IS into level competencies. In most cases, competencies are analyzed further into objectives. The analyst uses goals, subgoals, and objectives.

Affect and Inquiry

The affective goal has been structured into separate hierarchies for each of the four subgoals: attitude towards science learning experiences, attitude towards science and scientists, attitude towards scientific inquiry, and attitude towards inquiry as a way of thought (see Appendix B, Charts 4 to 8, pages 71-77). The rationale for this is that attitudes are felt, expressed, and observed towards each phenomenon separately.[7] Similarly, it was necessary to construct separate hierarchies for each of two subgoals of the inquiry goal because one facet of the goal relates to the processes of scientific inquiry, the other to the ability to carry out inquiries (see Appendix B, Charts 9 to 11, pages 78-86).[8]

Like the student self-direction and co-evaluation goals, the affective and inquiry goals are conceived as goals toward which the student is expected to move. Again, a relative concept of mastery is evident. The affective goal aims at helping the student to <u>develop</u> attitudes, to learn to value science for its contributions to man's intellectual growth and to society, to enjoy his or her learning experience in science, and to develop an informed attitude towards scientific inquiry. The inquiry goal aims at helping the student to <u>become</u> skillful in the processes of scientific inquiry and in carrying out inquiries.

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[7] For each terminal subgoal of the affective goal, the hierarchies are constructed with each of the IS levels, A through E, charted consecutively from the bottom to the top of the hierarchy. The code outside the box refers to the affective level of each objective according to Klopfer's structure of the affective domain for Individualized Science (Exhibit 1, page 42).

[8] For each objective in the processes of scientific inquiry hierarchy, Chart 10, the unit title is indicated in the lower right-hand corner of the objective's box. The code outside the box indicates the IS taxonomy level of the objective according to Klopfer's structure of the cognitive domain for Individualized Science (Exhibit 2, page 43).

The subgoals of the affective goal are viewed as falling into two categories. The first of these is related to attitude towards science and is charted in three hierarchies, each terminating in a subgoal towards which the attitude development is directed. The three subgoals are: attitude towards learning experiences in science, attitude towards science and scientists, and attitude towards scientific inquiry. The second category of the affective goal goes beyond attitude towards scientific inquiry to inquiry as a way of thought. This subgoal may be considered the affective dimension of the inquiry goal or the inquiry dimension of the affective goal.

The means of determining whether or not affective objectives have been attained are built into their expression. For attitude towards science learning experiences (see Chart 5, page 72), the student would be "observed in the classroom." The behavior to be demonstrated falls into three major categories, charted as hierarchy branches: performance of volunteer activities and reports on them (action); satisfaction in doing lessons and optional investigations (feelings); and pride in the care used in carrying out activities and lessons (feelings as they affect action). The three hierarchy branches represent not only different behavior categories, but also different mixes of affective/cognitive and intellectual/observable behavior.

Attainment of the subgoals dealing with informed attitudes towards science and scientists, towards scientific inquiry, and towards inquiry as a way of thought is assessed both by observing behavior in the classroom and by questioning students about their learning experiences in science. Student responses concerning science and scientists (see Chart 6, page 74) would fall into the categories represented by the three branches of this heirarchy: the study of the natural world as science's primary activity, interdependence of science and society, and differences among scientists and what they study. For an informed attitude towards scientific inquiry (see Chart 7, page 75), four branches of the hierarchy demand different competencies: one related to observation, one to interpretation and the need for accuracy, one to measurement, and one to the cumulative and revisionary nature of scientific inquiry. Finally, attitude towards inquiry as a way of thought (see Chart 8, page 77) calls upon four classes of competency represented by hierarchy branches: questioning, finding a means of answering the questions, finding alternative procedures, and extrapolating from one inquiry experience to a similar, but different experience. These demand successively more initiative and overt effort.

In charting the hierarchies, some objectives which are at the same affective taxonomy level may be organized vertically rather than on the same horizontal plane. The reason is that, within the same affective taxonomy level, the student's behavior may require greater or lesser degrees of motivation, overt expenditure of effort, or self-direction. For example, in the affective subgoal hierarchy for attitude towards science learning activities, to "work voluntarily on an elective activity or alternative unit" would demand less independent, undirected effort than to "consider questions and problems in Some Things to Think About" (open-ended questions at the end of each unit). The latter would, in turn, demand less sustained, organized effort than to "report to the teacher or other students." Although these three behaviors are all at Level B.2 of the affective taxonomy (see Exhibit 2, page 43), they have been charted sequentially because they are progressively more self-directive.

Level of self-directiveness, then, may be a consideration for charting objectives within a hierarchy. However, for any given child this sequence may not represent the optimal progression. For an extrovert, reporting both formally and informally might be a natural activity; for an introvert, pondering questions and problems in Some Things to Think About might be more attractive. In this case, the vertically hierarchical positions of objectives do not represent a necessary dependency relationship, but they do reflect a relationship with another of the curriculum's goals. Nevertheless, even if self-direction were not an explicit goal of IS, the demands made on the students by these objectives would lead to the construction of similar vertical sequences in an accurate plotting of the curriculum structure.[9]

The inquiry goal is divided into two subgoals: use of appropriate processes of inquiry, and progress in developing the ability to carry out inquiries (Appendix B, Charts 10 and 11, pages 79-86). The hierarchy for the second subgoal begins with IS Level C and has been constructed on the basis of independent investigations of Levels C, D, and E. Its branches, of course, are much the same as those of the attitude towards inquiry hierarchy: questioning, posing problems for investigation, and proposing procedures for investigating problems. The student must be aware of the necessity of the elements in order to be able to carry them out. In this hierarchy, as in all the hierarchies under Goals II through V, the specified behaviors at each IS level may be termed milestones, or behavioral evidence of progress towards the terminal goals.

The several hierarchies presented up to this point highlight one of the distinctive features of IS, the careful attention given the affective, inquiry, and self-management goals. These goals are often espoused by curriculum designers but seldom are they as carefully structured as the subject-matter content goals. A distinctive feature of IS is it's careful structuring of the components of self-direction,

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[9] It must be assumed that each level of each dimension or branch of the affective hierarchies is attained through a series of instructional experiences. Both the level at which there is an increment and the experiences used to attain it will vary from student to student. The desired behavior may be demonstrated occasionally rather than consistently, but progress towards goal attainment at each level of the curriculum is expected. This is indicated by the lines which connect all the boxes of one affective level to all the boxes of the next level.

co-evaluation, affect, and inquiry, as shown in Charts 2 through 11 (Appendix B, pages 68-86). Each learning task involves more than one goal. In the IS program, the appropriateness of levels of each domain involved in a single task has been carefully and explicitly considered, and appropriate sequences have been incorporated into the design. IS represents an integrated pursuit of learning goals, as the hierarchies delineate.

Scientific Literacy

Three illustrative hierarchies are included for the scientific literacy goal (see Appendix B, Charts 12 to 15, pages 87-107): one for measurement terminology, one for the concept of energy, and one for systems concepts. The progression of objectives from the bottom of each hierarchy to the top follows the order of units in the several IS levels.

The scientific literacy goal aims "to build a solid base of knowledge and understanding of and about science which the student will need to function in an increasingly complex world" (Klopfer, Note 5). Here, rather than centering on the process of becoming informed and self-directive, IS focuses on the conceptual structure of science. Choice from a variety of resource materials and different examples provides for adaptability to individual students. The materials are adaptive to an individual's learning style or preference, interest, and concept level.

One of the illustrative hierarchies constructed for scientific literacy is that for measurement terminology (Chart 13, pages 88-94). Because each IS unit dealing with measurement terminology employs those terms which are related to the science content of that particular unit, this hierarchy was constructed with several branches. At Level E, for instance, one branch shows the development of terminology related to the science of nutrition, another branch deals with temperature, mass, force, and work. At Level C, length, mass, volume, and temperature are treated as separate branches to show clearly how they develop.[10]

An example of how decisions are made about placement in the hierarchy is furnished by the developers' stated objective: "The student states that the only certain way to determine which one of a pair of individuals has the greater calorie requirement is by measurement." This is placed at the top of a series of objectives on nutrition measurement terminology, although the word "states" could mean that the student only repeats a memorized statement. The wording of the objective was retained as the developers wrote it, but it was placed in the hierarchy in the position of a principle on the basis of an in-depth analysis of the lesson materials. It was found that this principle was taught carefully, with cues gradually faded, over several different learning experiences. These included the statement that "only by measuring can you be sure," a discussion of all the differences that affect amounts of energy needed by an individual, and a discussion that indicated the unreliability of any other means than measurement. All of these experiences contribute to teaching the need for measurement in judging calorie requirements, hence the placement of the objective at the top of the series.

The illustrative hierarchies for energy and systems (Charts 14 and 15, pages 95-107) structure the mainstream unit objectives that attend to these science concepts. Each hierarchy sets forth an array

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[10] The objectives structured are from the lessons in the mainstream units only, although the IS curriculum also includes alternative pathways units and a variety of learning activities in addition to those contained in the lessons. These are usually listed as related resources in each unit and provide many more experiences with the content of the unit.

of examples demonstrating the range of instances provided in the IS lessons.

The introduction of energy as a discrete concept begins at Level C.[11] Formal study of energy is begun at Level E in "attempting to answer the question, 'What is energy?'" At Levels C and D, only those objectives that explicitly deal with energy are structured; at Level E all objectives are structured. Systems concepts are introduced at Level C and continued at Level D with a study of burning and subsystems involved. At Level E the student studies energy as a subsystem of biological systems. The way some of the same lessons build towards different science concepts (energy; systems) is graphically demonstrated by comparing the energy and systems hierarchies and noting that some of the same objectives appear in both hierarchies.

Energy may be used as an example to show how the developers of IS have built the conceptual framework of scientific literacy (see Chart 14, pages 95-102). By attending simply to the categories of student behavior, one can quickly scan this process. In dealing with the energy concept, the student (a) names, defines, identifies; (b) gives examples, classifies, describes; (c) explains, demonstrates, identifies attributes, distinguishes; (d) selects, orders; (e) reads charts, writes equations; (f) describes subsystem interactions, demonstrates processes; and (g) states or demonstrates concepts, principles, and generalizations. At Level C the student observes manifestations of energy and changes brought about by adding or removing heat. By Level D the student relates respiration to burning, and has begun to identify different

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[11] It was determined that the concept begins here because the developers speak in the Level C teacher's manual of "rudimentary concepts and observations" of manifestations of energy at Level C and confirm that the concept is more fully introduced at Level D (p. 173). In the Level D teacher's manual, they speak of "introducing ideas about energy exchange" (p. 26).

kinds of energy (heat, light, sound) and to explain such changes as evaporation, melting, dissolving, and sublimation by kinetic molecular theory.

At Level E, as the hierarchy clearly shows, the range of instances of energy has expanded. The formal study of energy has begun with identification of the attributes of energy and with learning experiences with a wide variety of forms of energy (heat, chemical, kinetic, sound, electrical, light, elastic, gravitational). The concepts, principles, and generalizations are built through a variety of experiences, and the student demonstrates his or her acquisition of the concepts by synthesizing, creative activities (e.g., writing an essay on what life would be like without the sun's energy, or how life would be different if all the coal and petroleum on earth were used up).

Evaluation of IS on the Basis of Curriculum Analysis

The description of the hierarchies constructed for each of the goals of Individualized Science has attempted to point out some of the fine points of the curriculum revealed by the hierarchy construction process. The construction procedures have been explained in order to clarify the significance of each branch, each level, and each linking vertical or horizontal line. By examining the hierarchies, significant information about certain aspects of the instructional process can be inferred. For example, in the development of a broad and fundamental concept, the hierarchy clearly shows the sequence in which instances of the concept are introduced, the range of instances of the concept, and the way principles and generalizations are built out of component concepts.

The advantage of such an economical method of presenting a tremendous amount of information about a highly complex curriculum should not be underestimated. However, it is important to note that in the process of constructing hierarchies, the investigator gains more information about the curriculum that can be immediately discerned in the hierarchies themselves? Some of this is relevant to the claims of the developers about their program and, therefore, to its evaluation. Each of the claims made for IS will be examined in light of the information gleaned during the hierarchy construction process.

Adaptive Environment

One of the first claims of the IS developers is that they have produced a multifaceted program with many resources which make possible an "adaptive environment," that is, an environment that "has the capability of matching instruction to various characteristics of individual learners" (Champagne & Klopfer, Note 2, p. 2). The developers constructed a table displaying the many facets of the program (see pages 44-45) which shows how provisions are made for variations in goals, materials, instructional units, settings (whole group, small groups, individuals), teaching focus (subject matter, process, values), mode[12] (lecture, discussion, laboratory, programmed materials, self-instructional materials), and locus of responsibility for evaluation and decision making. The developers describe how these variations provide for individual differences in acquired knowledge, interest, attitudes, and intelligence (Champagne & Klopfer, Note 2). They do not claim to know how to provide for variations in cognitive style or cognitive development, the mechanisms for which, they maintain, "are just beginning to be explored." However, they suggest that different social settings and methods (didactic, guided discovery, inquiry) accommodate to some of these differences. They also show, in tabular

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[12] The developers use the term "instructional strategy" in which they include didactic, guided discovery, and inquiry. The writer prefers to use "method" for this dimension of a curriculum, reserving the term "instructional strategy" for those techniques of instruction that have firm research-based evidence of effectiveness.

form, the program's many resources and how these relate to its goals, which they claim adapt instruction to both learner differences and the content to be learned.

The IS program does provide such a wealth of resources and such a variety of instructional options that the instructional environment appears highly capable of adapting to individual needs. The learning resources chart (see Appendix A, pages 44-45) provides some indication of the range of these resources and options. IS consists of mainstream units, which teach the program's behavioral objectives, and alternative pathway units, which go beyond these objectives to stretch the child's capabilities and stimulate his or her interests. The hierarchies do not attempt to structure these alternative units. Without them, the program is adaptive; with them, it has the capability of being remarkably adaptive.

In creating a program which would furnish the adaptiveness demanded by the individual differences in elementary school children, the developers confronted many curriculum design problems. Their solutions suggest some of the elements that should be attended to in designing an adaptive curriculum. For example:

1. To provide a variety of settings to meet the preferences of the students and the demands of instructional objectives, the develcpers designed student activities which could be done alone, with the teacher, with one or more students, or as group activities with the teacher.

2. To keep track of a class of students, each with his or her own plan of study, the developers provided planning booklets for each student to record plans and progress and class management sheets for the teacher to keep track of students' plans and progress and to assemble those ready for Directed Group Activities.

3. To ensure that this highly complex program would stand alone without teacher support from aides, implementers, or other personnel and could thus be successfully disseminated, a myriad of teacher props were furnished and structured instruction in self-management was provided for the student.

4. To avoid the problems associated with initial implementation of an innovative curriculum and to relieve the kinds of anxieties that many teachers express at the prospect of attempting to individualize instruction, a number of teacher props were designed. These props include classroom model charts, materials storage procedures, lists of materials needing replenishment after each lesson, descriptions of how to assemble materials, and management information for each level, including possible routes that a student could follow.

Self-Directed Learning and Evaluation

To meet the challenge of a world of change and the need to acquire new skills and knowledge, the child must become a lifelong learner. IS provides mechanisms for children to plan their science activities, to manage their own instructional materials, and to take part in the assessment of their learning. "It also provides opportunities for the child to make selections from alternative learning resources and from alternative units of study" (Champagne & Klopfer, Note 2, p. 1). The program attempts to develop attitudes towards learning by teaching children how the instructional system functions and giving them a sense of participation in decision making (Klopfer, 1971a, 1971b; Champagne & Klopfer, Note 2).

All of these claims are reflected in four of the program goals: affective, inquiry, self-direction, and co-evaluation. The hierarchies for these goals indicate that the science lessons offer opportunities structured in small steps, which permit self-management, self-assessment, and choice of learning resources and, beginning at Level D, of alternative units. In the early levels, the program provides instruction in science vocabulary, the learning-to-learn skills of observing, sorting, measuring, describing, ordering, classifying, collecting data, recording data, and interpreting bar graphs. The student has an opportunity to acquire skills and processes of inquiry and is exposed to learning experiences designed to provide an informed attitude towards science and scientists, science learning experiences, and scientific inquiry.

If understanding the learning system gives the students "a sense of participation and control," teaching them the mechanics for developing such understanding should foster this sense of control. The program supplies a Start Unit for Levels A and B and a Launch Unit for Levels C, D, and E, which teach the mechanics. The Start Unit teaches how to operate a recorder, follow directions, use a planning sheet, and find materials, and it tests prerequisite skills such as recognition of numbers and letters. The Launch Unit teaches how to manage materials, score tests, and select student activities and also provides an introduction to new concepts, vocabulary, and instruments.

In programming these goals, the science developers have encountered and solved the following problems related to adaptive instructional design:

1. To permit informed decision making by students, the Directed Group Activities, managed by the teacher, present an overview of unit choices. From Level D on, student seminars include seminar books with directions, which permit student self-direction. These seminars also provide opportunities for students to use, orally, the vocabulary of the subject they are studying individually.

2. To provide for social interaction in an individualized program, the variety of resources from which the student selects includes projects on lesson concepts,

games, etc., which allow for student interaction. The Directed Group Activities include group discussion of concepts, filmstrips, and the lives of well-known scientists.

3. To provide necessary information on subject matter content and/or directions on activities that some children might not be able to read, optional read-along tapes and illustrated lessons impart science or planning information and oral directions for activities.

4. To provide for exploration and challenge with students of varying interests and abilities, Invitations to Explore, Miniature Explorations (MinEx) and Self-Initiated Independent Activities challenge, while How-to-Booklets remind students how to manage independently. The MinExs have problems on the cover, which some students can attempt to solve on their own as well as pictures of experiments inside which children can model. Open-ended questions encourage further inquiry.

5. To encourage the teacher to permit student self-management and co-evaluation, the developers have built teacher props into the materials of each unit. To assist students in self-management, they are provided with answer keys and planning notes on how to get materials, return them properly, make and carry out a plan. Placement test questions are keyed to lesson content and help determine what to do next.

   A teacher's manual supplies course information and directions. The teacher is encouraged to take the opportunity to discuss with the student his or her progress in the program, and information is given on how and when to do so. The teacher's alternatives, depending on student progress, are pointed out and hints are given about how to help students evaluate the appropriateness of their choices.

   In addition, the curriculum reminds the teacher to record students' special problems and activities, concepts they would like to continue studying, and the activities they complete.

> Finally, the "How-To" student booklets provide the teacher, who may be fearful of the dangers of self-management, with a mechanism for reminding students of safety precautions as well as other self-management skills.

Relevance

The content of Individualized Science, the developers claim, is relevant to the social circumstances of today and the foreseeable future, emphasizing cultural aspects of science and the interaction of science and society. The content, they assert, capitalizes on the interests of the child and seeks "to give each child some methods and skills for attacking the questions which tug at him and some useful framework into which to fit the answers" (Klopfer, 1971b, p. 26).

While all of the goals are related to these claims, the scientific literacy goal is particularly relevant. The interactions of science and society are explicitly attended to, mainly through the filmstrips on the lives of scientists. In addition, much of the content is selected to provide the scientific knowledge necessary for helping the student to deal with social problems of the present and future.

The physical and biological sciences are highly relevant to the search for solutions to such problems as overpopulation and threats to ecological balance. The hierarchies show that at each level students are asked to describe contributions of scientists to their society. The physical and biological science curriculum objectives include sequences on the composition of the atmosphere, the human respiratory system, air pollution, the digestive system, and nutrition. A major area of study in IS is energy which, of course, has broad social implications and current interest. The student is asked to consider these implications and write about them.

The claim that each child is given methods and skills for attacking questions "that tug at him or her" is adequately justified. The early lessons, which teach skills of observation, measurement, and classification, are carefully sequenced. The goals of informed attitude toward, and eventually commitment to, inquiry and the ability to carry out inquiries are carefully attended to at each level, as the hierarchies show. The developers anticipate that by Level C, some students will go beyond strictly scientific inquiry and begin to develop a commitment to inquiry as a general way of thought. The developers apparently expect an "Aha!" effect, since in the affective domain the IS levels from C to E progress relatively rapidly, from A. 1 to A. 3 on the affective taxonomy (see Exhibit 1, page 42). Once students become aware of the processes of inquiry--asking a question, seeking a way to answer it, proposing alternative procedures, and extrapolating from experiences in dealing with one problem to a similar problem--they are expected to make progress in their ability to carry out inquiries. This progress can be investigated by examining student performance in the independent activities.

Again, attention to these program aims has led the developers to solve other curriculum design problems in the process:

1. To maintain children's interest and motivation to learn, the lessons address themselves to children's concerns about their own bodies and answer many of the kinds of "why?" and "how?" questions children naturally ask about themselves and their environment.

   Many of the explorations are written in puzzle form to make them especially appealing to children. For example, the story of Archimedes' search for a way to find the volume of the King's crown introduces a MinEx which asks the student to solve the same problem. After solving it, the student is encouraged to find an alternate way of making the same measurement. Another MinEx asks students how to use a plastic bag to raise a small book off a table without touching the book or lifting the bag. A third asks the student to predict whether a paper towel will get wet if it is pushed into the bottom of a vial which is then pushed open end down into some water.

2. To help the teacher who does not know the science content, the teacher's manual provides an overview of the content and a rationale for its use. In addition, there are notes to the teacher on things that pose special difficulty for students. Themes emphasized in the filmstrips are listed. The teacher is given suggestions on questions to ask and why to ask them, and references are made to learning theory sources for teachers who want to learn more about how children acquire concepts.

Possible Further Claims

There are additional elements in IS which might well have elicited claims by the developers, but did not. For example, IS is adaptive to the local school situation as well as the individual student. Two different classroom models are possible: regularly scheduled at 90 minutes per week, and flexible, involving large blocks of time.

It is possible, because of the very carefully specified structure of science content on which the program is based, to use a computer to generate tests. Whatever category of behavior or knowledge the teacher, evaluator, or product purchaser is interested in knowing about can be tested, because each objective is carefully coded to the structure of science as defined by the developers.

Finally, the program makes no claim about interpersonal skill training. However, the care with which instruction is designed for the sharing and proper handling of materials indicates that this is an inferred objective. The diversity of instructional situations also encourages social interaction by providing the student an opportunity to work with different individuals or different groups of children.

Theoretical Basis and Instructional Strategies

The developers of IS call their program eclectic because they borrow from a variety of theoretical bases for the research underlying their instruction. They refer explicitly to Gagné, Bruner, Piaget, Ausubel, and Glaser (Champagne & Klopfer, Note 2). They could have referred to Dewey, Skinner, Klausmeier, Schwab, Bloom, and Krathwohl, among others. Instructional strategies used throughout levels are clearly influenced by each of these theoreticians and researchers.

One element that characterizes the IS curriculum and stands out as its greatest strength is the care with which it follows the fundamental structure of science. This gives it its consistency and makes feasible the integrated pursuit of goals. It facilitates the building of the concepts of systems, energy, kinetic molecular theory, and biological adaptation as recurring themes, built and strengthened unit by unit. This element of structure, which owes much to Schwab (1964) and Bruner (1960), is the element and the strength that comes across most clearly in the scientific literacy hierarchies.

The ideas of Piaget are reflected in the way the lessons attend to the child's development in abstraction, attention span, and concept learning. At the early levels, when the child might be expected to be at the state of concrete operations, the learning experiences are concrete and short. The later lessons become longer and more abstract. The level of abstraction is another program aspect clearly illustrated by the hierarchies.

The sequencing of instruction in IS shows the influence of other theorists also. The taxonomic levels of Bloom (1956), somewhat modified by the developers, and of Krathwohl, Bloom, and Masia (1964) are clearly apparent in the defining and sequencing of objectives. The building from concepts to principles to generalizations shows the influence of Gagné (1965) and, again, of Schwab (1964) and Bruner (1960). The progress from single to combined skills stems from Dewey (1933) and Piaget (1969). The progression from instances with few irrelevant attributes to those with many can be traced to Bruner, Goodnow, and Austin (1962), Glaser (1968), and Klausmeier and Hooper (1974).

These writers undoubtedly would support the building of the concepts of energy and systems, as revealed by the hierarchies, as examples of their instructional theories at work.

Glaser's design model is clearly apparent in the structured curriculum model: testing procedures (integrated into the curriculum), discrete materials for teaching each objective, and procedures for individual progression through the program.

Advance organizers (Ausubel, Note 6) were used throughout the curriculum, both in the form of overviews of what is to come (Directed Group Activities) and in the form of fundamental organizing concepts, taught early and built upon. There is evidence that students' learning and retention is better with such assistance (Bloom, 1971; Gagné, 1965; Klausmeier & Harris, 1966; Ausubel, Note 6).

To demonstrate attainment at the level of practical application, which is defined in IS as an element in the definition of "understand," the Bloom (1956) criterion of "use in a novel situation" is employed. The theories of Skinner and other behaviorists and the programming work of Glaser and colleagues (Taber, Glaser, & Schaefer, 1965) appear in the use of such techniques as cues, prompts, and successive approximations of desired terminal behaviors (Solomon & Holland, Note 7).

Questions for Further Research

As has been suggested, many questions arise for further evaluative research as a by-product of the hierarchy construction process. Some of these questions follow: Are the behaviors shown in the self-management and co-evaluation hierarchies the essential components of self-directed, self-evaluative learning? Are these the optimal sequences for attaining it? Are these elements the appropriate ones for the developmental level of the students? For example, is it appropriate, at Level D (about fourth grade), to initiate student responsibility for arranging an interactive mode of learning in a seminar and carrying out a role in it? Should other objectives for using human resources for learning precede the seminar objective at Level D?

Do students who have completed IS Level A demonstrate the ability to carry out the following behaviors in other classes which do not teach self-management, e.g., getting their own materials and returning them to the proper places and following written or verbal direction which they can read and/or understand? Do students who have been in this program through Level D demonstrate greater decisiveness in other classes (quicker, reasoned decisions) when given a choice between several alternative learning activities than do students who have not had this learning experience? Should there be specific lessons to teach students to analyze in addition to the student and teacher management props which facilitate such analyses?

Do students who have studied IS use the inquiry processes learned in science in investigations in other school subjects outside of science? Is there a relationship between the number of additional related resources a student elects to use and his or her achievement in science? How do students who have completed all levels of IS compare with other science students in level of scientific literacy as these terms are defined specifically by the developers of IS?

The IS Model: Towards an Adaptive Environment

Lindvall and Cox (1969) have defined a structured curriculum model, which has been the basis for individualizing instruction from the Winnetka Plan to IPI, as having the following five elements:

1. Sequences of instructional objectives to define the curriculum.

2. Instructional materials to teach each objective.

3. An evaluation procedure for placing each pupil at the appropriate point in the curriculum.

4. A plan for developing individualized programs of study.

5. A procedure for evaluating and monitoring individual progress. (p. 161)

The interim report on the goals and scope of Individualized Science (Klopfer, Note 5) listed three requisite conditions for individualized programs with diverse goals:

1. All students need not have the same learning experiences and a student does not need to work on all units and activities.

2. There must be a common core in which every student is expected to achieve mastery.

3. There must be a rich variety of alternative resources which facilitate self-direction and co-evaluation.

Analysis of IS points up three other elements that appear to be essential to the flexibility of an individualized curriculum model:

1. A process concept of mastery which accommodates attitude, process, and achievement expectations to individual differences.

2. Identification of the underlying structure of the discipline to establish appropriate categories within which instructional activities can be developed. This makes a range of experiences feasible, and challenges are always available to the student (see Appendix A, Exhibits 2 and 3, pages 43-45).

3. Explicit attention to providing self-management opportunities in the instructional management system.

Adding the elements identified by the analysis of IS to the structured curriculum model defined by Lindvall and Cox (1969) results in a more complete list of the elements that define an adaptive environment:

1. Sequences of instructional objectives based on the structure of the discipline.

2. Instructional materials which provide:
    a. a common core in which every student is expected to achieve mastery.
    b. a rich variety of alternative resources, making feasible individualized programs of study.
3. A management procedure permitting students to participate in:
    a. selecting appropriate units and activities in which to work.
    b. monitoring their own progress and evaluating their own work.
4. A process concept of mastery, accommodating expectations for attitude, skill, and concept attainment to individual differences.

Conclusion

This paper has described how the PIC Model was employed to analyze Individualized Science. The purpose of the analysis was to assess the extent to which the curriculum materials attend to those aspects of instruction its developers claim it addresses and to describe by what procecures they are addressed.

On the basis of a careful examination of the IS curriculum materials during the process of constructing hierarchies and an examination of the hierarchies themselves, these conclusions are drawn: The goals of IS are supported in the quantity and range of the materials offered. Many of the problems of adaptive instructional design have been solved and an adaptive design model may be inferred from the product. The instructional strategies employed are supported by research and are appropriately used.

One of the developers suggested that, "Perhaps what an elementary school science program really can accomplish is to make the child's world appear less contradictory to him, so he may feel safe in it" (Klopfer, 1971b, p. 27). The present analysis indicates that the Individualized Science program has produced a variety of instructional materials and a carefully integrated management system which provides the necessary curricular elements for accomplishment of this aim.

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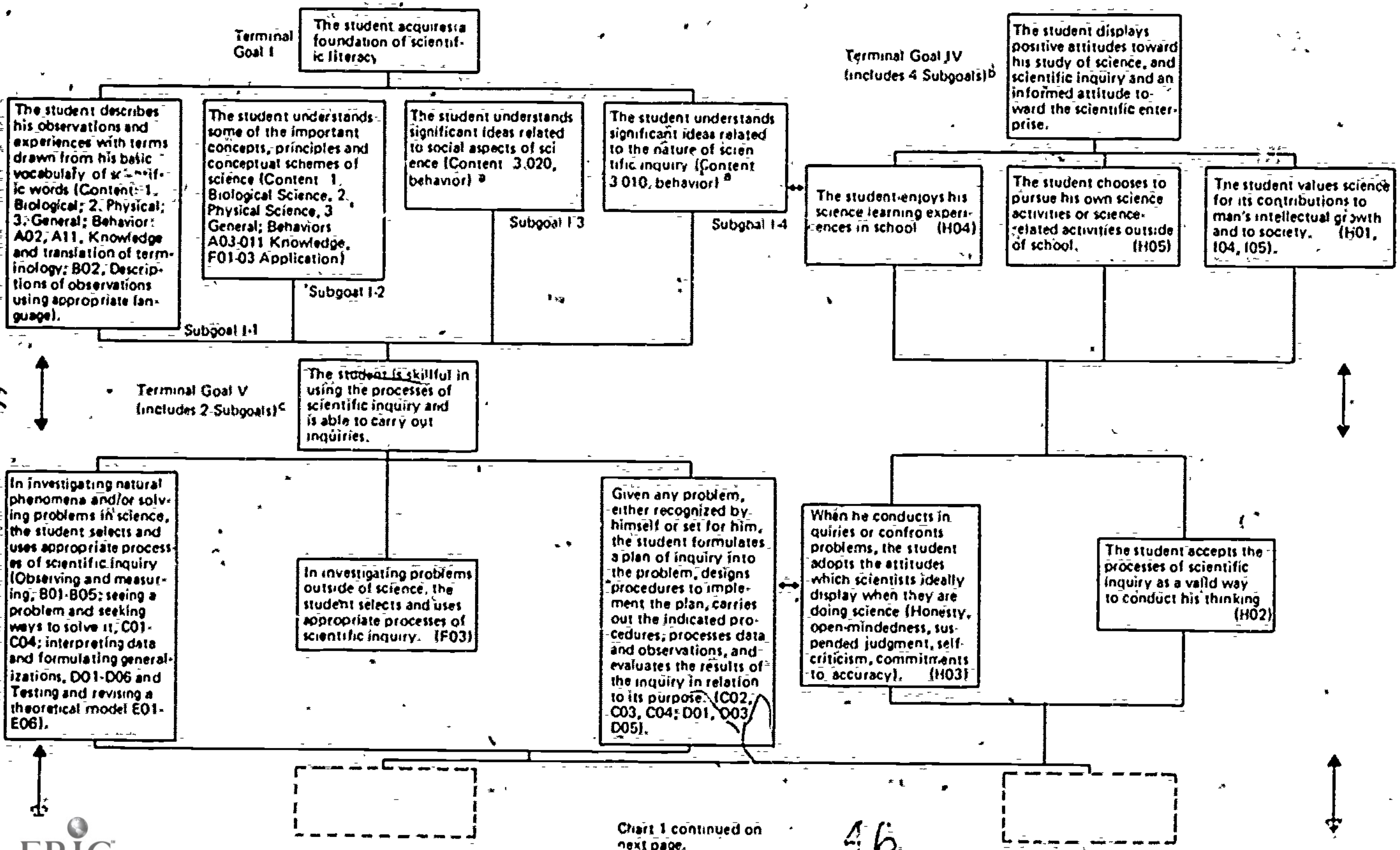
APPENDIX A "EXHIBITS" PAGES 59-64 REMOVED PRIOR TO BEING SHIPPED TO EDRS FOR FILMING DUE TO COPYRIGHT RESTRICTIONS.

APPENDIX B

HIERARCHY CHARTS

CHART 1

Curriculum Analysis of Individualized Science. Overview of the Goals



Terminal Goal I

The student acquires a foundation of scientific literacy

The student describes his observations and experiences with terms drawn from his basic vocabulary of scientific words (Content: 1. Biological; 2. Physical; 3. General; Behavior: A02, A11. Knowledge and translation of terminology; B02, Descriptions of observations using appropriate language).

Subgoal I-1

The student understands some of the important concepts, principles and conceptual schemes of science (Content 1. Biological Science, 2. Physical Science, 3 General; Behaviors A03-011 Knowledge, F01-03 Application)

Subgoal I-2

The student understands significant ideas related to social aspects of science (Content 3.020, behavior) [a]

Subgoal I-3

The student understands significant ideas related to the nature of scientific inquiry (Content 3 010, behavior) [a]

Subgoal I-4

Terminal Goal IV (includes 4 Subgoals)[b]

The student displays positive attitudes toward his study of science, and scientific inquiry and an informed attitude toward the scientific enterprise.

The student enjoys his science learning experiences in school (H04)

The student chooses to pursue his own science activities or science-related activities outside of school. (H05)

The student values science for its contributions to man's intellectual growth and to society. (H01, 104, 105).

Terminal Goal V (includes 2 Subgoals)[c]

The student is skillful in using the processes of scientific inquiry and is able to carry out inquiries.

In investigating natural phenomena and/or solving problems in science, the student selects and uses appropriate processes of scientific inquiry (Observing and measuring, B01-B05; seeing a problem and seeking ways to solve it, C01-C04; interpreting data and formulating generalizations, D01-D06 and Testing and revising a theoretical model E01-E06).

In investigating problems outside of science, the student selects and uses appropriate processes of scientific inquiry. (F03)

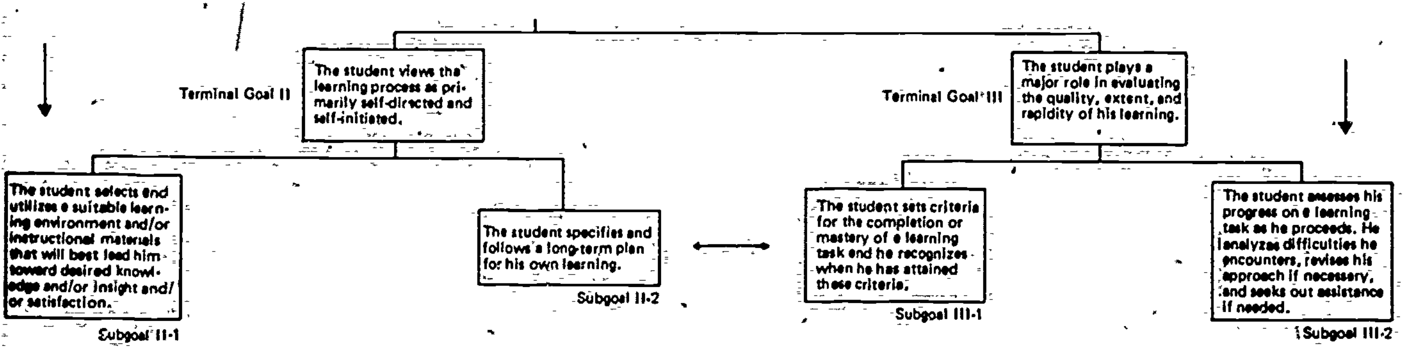
Given any problem, either recognized by himself or set for him, the student formulates a plan of inquiry into the problem, designs procedures to implement the plan, carries out the indicated procedures; processes data and observations, and evaluates the results of the inquiry in relation to its purpose. (C02, C03, C04; D01, D03, D05).

When he conducts inquiries or confronts problems, the student adopts the attitudes which scientists ideally display when they are doing science (Honesty, open-mindedness, suspended judgment, self-criticism, commitments to accuracy). (H03)

The student accepts the processes of scientific inquiry as a valid way to conduct his thinking (H02)

Chart 1 continued on next page.

Chart 1 (Cont'd)



The student views the learning process as primarily self-directed and self-initiated.

The student selects and utilizes a suitable learning environment and/or instructional materials that will best lead him toward desired knowledge and/or insight and/or satisfaction.

The student specifies and follows a long-term plan for his own learning.

The student plays a major role in evaluating the quality, extent, and rapidity of his learning.

The student sets criteria for the completion or mastery of a learning task and he recognizes when he has attained these criteria.

The student assesses his progress on a learning task as he proceeds. He analyzes difficulties he encounters, revises his approach if necessary, and seeks out assistance if needed.

Note. The goals are from "Goals and Scope of IPI Science" by L. E. Klopfer, unpublished paper, University of Pittsburgh, Learning Research and Development Center, 1970.

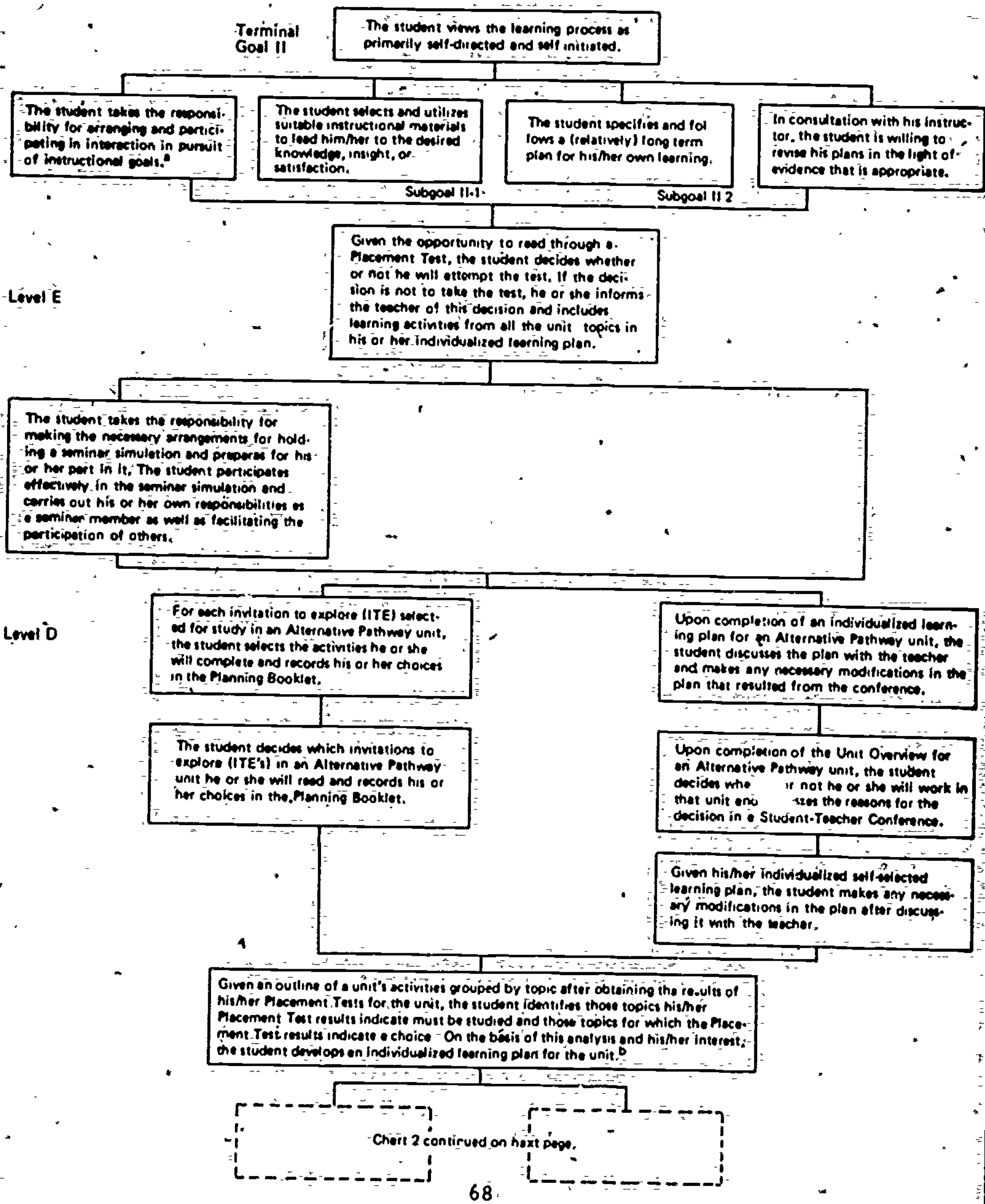
[a] In IS, the word "understand" is used as a shorthand expression in stating terminal behaviors and means that the student has knowledge about and can apply his knowledge about an idea, principle, process, or institution.

[b] This was "positive attitudes" in Klopfer's (1970) source, became "informed" in the commercial version. Positive seems appropriate for one set of subgoals; informed for another as they are expressed by the developers. Elsewhere, however, Goal IV is worded as in the commercial version, "informed."

[c] The components of the affective inquiry goals include out-of-school as well as in-school attitudes and behaviors which it is expected, but cannot be assumed, would be encouraged and supported by the curriculum. These two goals are, therefore, further broken down into school-related subgoals in separate overviews on pages 71 and 78.

CHART 2

Curriculum Analysis of Individualized Science: Hierarchy of Student Self-Direction Goal



Terminal Goal II

The student views the learning process as primarily self-directed and self initiated.

The student takes the responsibility for arranging and participating in interaction in pursuit of instructional goals.[a]

The student selects and utilizes suitable instructional materials to lead him/her to the desired knowledge, insight, or satisfaction.

Subgoal II-1

The student specifies and follows a (relatively) long term plan for his/her own learning.

In consultation with his instructor, the student is willing to revise his plans in the light of evidence that is appropriate.

Subgoal II 2

Level E

Given the opportunity to read through a Placement Test, the student decides whether or not he will attempt the test. If the decision is not to take the test, he or she informs the teacher of this decision and includes learning activities from all the unit topics in his or her individualized learning plan.

The student takes the responsibility for making the necessary arrangements for holding a seminar simulation and prepares for his or her part in it. The student participates effectively in the seminar simulation and carries out his or her own responsibilities as a seminar member as well as facilitating the participation of others.

Level D

For each invitation to explore (ITE) selected for study in an Alternative Pathway unit, the student selects the activities he or she will complete and records his or her choices in the Planning Booklet.

Upon completion of an individualized learning plan for an Alternative Pathway unit, the student discusses the plan with the teacher and makes any necessary modifications in the plan that resulted from the conference.

The student decides which invitations to explore (ITE's) in an Alternative Pathway unit he or she will read and records his or her choices in the Planning Booklet.

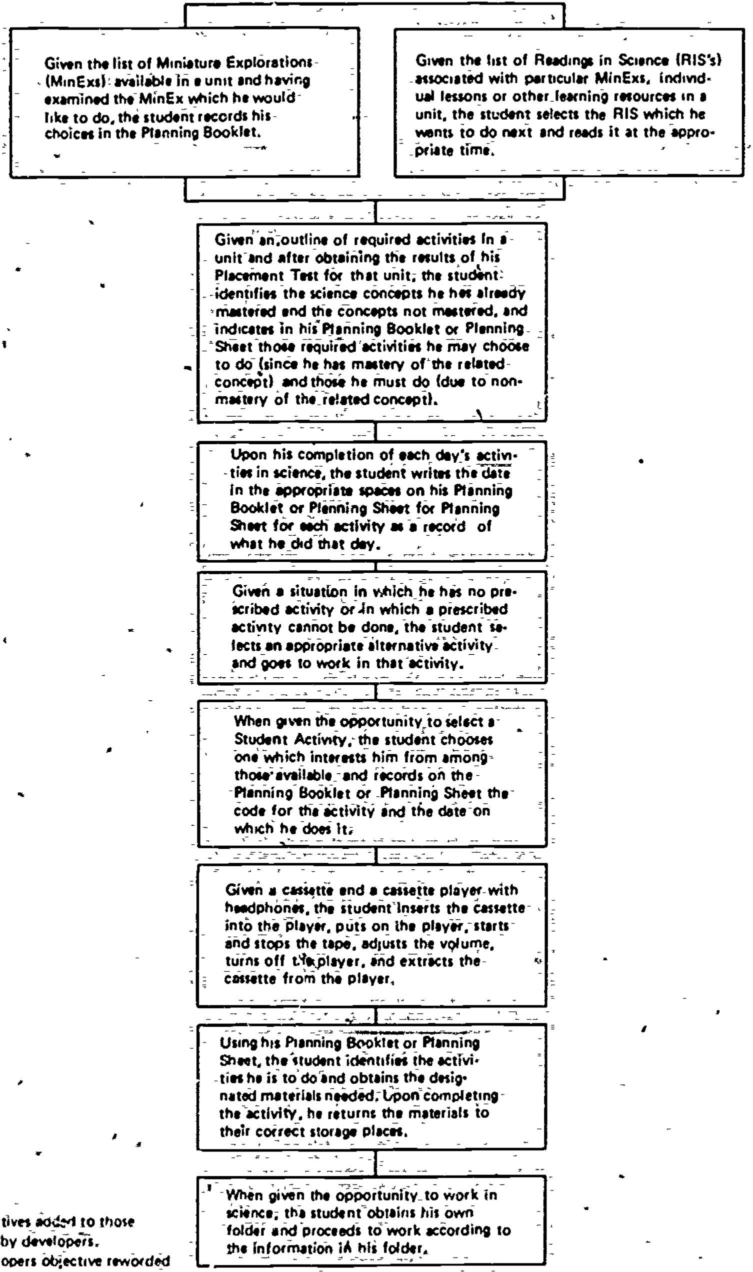
Upon completion of the Unit Overview for an Alternative Pathway unit, the student decides whe[illegible]r not he or she will work in that unit an[illegible]sses the reasons for the decision in a Student-Teacher Conference.

Given his/her individualized self-selected learning plan, the student makes any necessary modifications in the plan after discussing it with the teacher.

Given an outline of a unit's activities grouped by topic after obtaining the results of his/her Placement Tests for the unit, the student identifies those topics his/her Placement Test results indicate must be studied and those topics for which the Placement Test results indicate a choice. On the basis of this analysis and his/her interest, the student develops an individualized learning plan for the unit.[b]

Chart 2 continued on next page.

Chart 2 (Cont'd)



Given the list of Miniature Explorations (MinExs) available in a unit and having examined the MinEx which he would like to do, the student records his choices in the Planning Booklet.

Given the list of Readings in Science (RIS's) associated with particular MinExs, individual lessons or other learning resources in a unit, the student selects the RIS which he wants to do next and reads it at the appropriate time.

Level C

Given an outline of required activities in a unit and after obtaining the results of his Placement Test for that unit, the student identifies the science concepts he has already mastered and the concepts not mastered, and indicates in his Planning Booklet or Planning Sheet those required activities he may choose to do (since he has mastery of the related concept) and those he must do (due to nonmastery of the related concept).

Upon his completion of each day's activities in science, the student writes the date in the appropriate spaces on his Planning Booklet or Planning Sheet for Planning Sheet for each activity as a record of what he did that day.

Given a situation in which he has no prescribed activity or in which a prescribed activity cannot be done, the student selects an appropriate alternative activity and goes to work in that activity.

Level B

When given the opportunity to select a Student Activity, the student chooses one which interests him from among those available and records on the Planning Booklet or Planning Sheet the code for the activity and the date on which he does it.

Given a cassette and a cassette player with headphones, the student inserts the cassette into the player, puts on the player, starts and stops the tape, adjusts the volume, turns off the player, and extracts the cassette from the player.

Level A

Using his Planning Booklet or Planning Sheet, the student identifies the activities he is to do and obtains the designated materials needed. Upon completing the activity, he returns the materials to their correct storage places.

When given the opportunity to work in science, the student obtains his own folder and proceeds to work according to the information in his folder.

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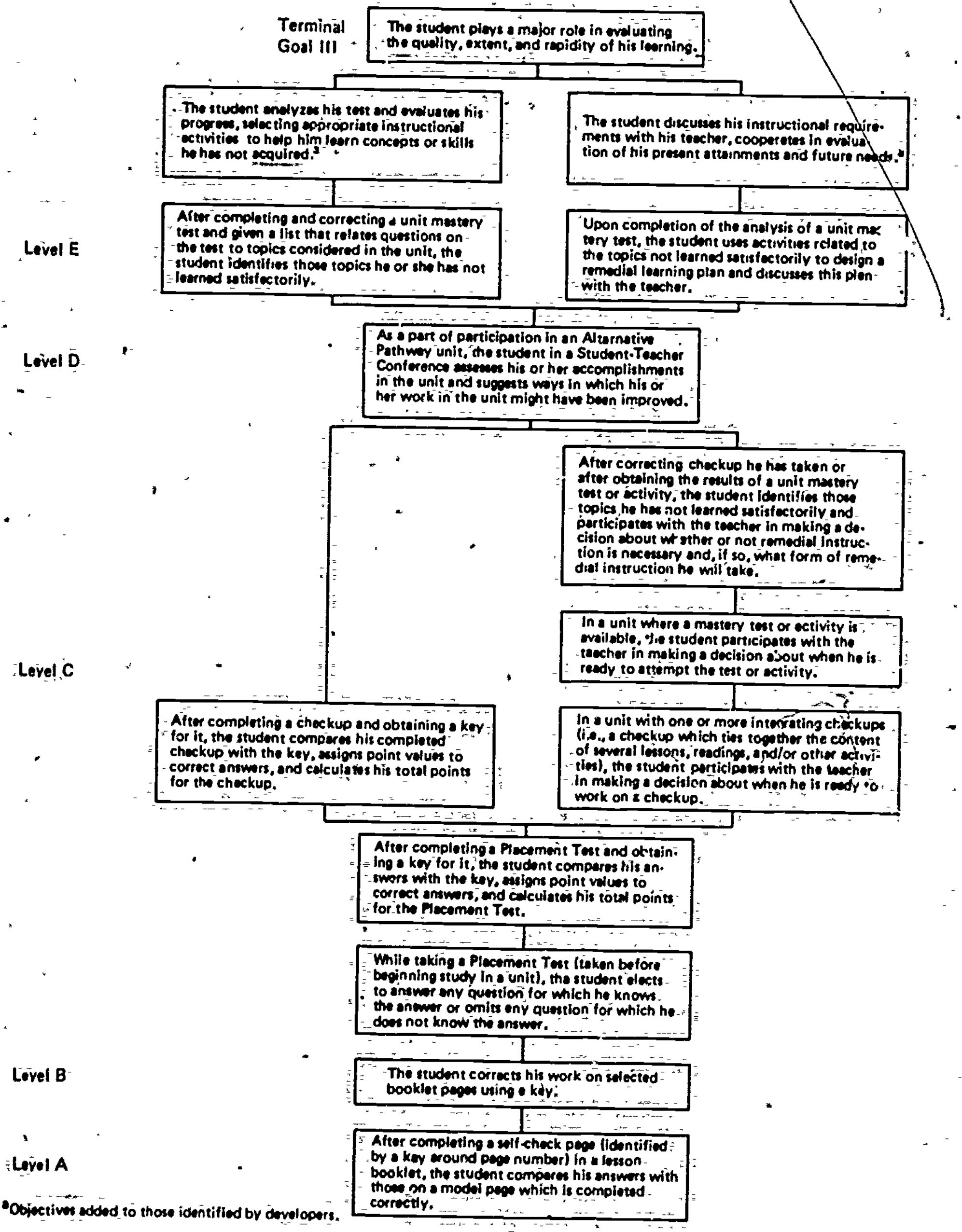
[a] Objectives added to those identified by developers.

[b] Developers objective reworded

CHART 3

Curriculum Analysis of Individualized Science: Hierarchy of Student Co-Evaluation Goal



Terminal Goal III

The student plays a major role in evaluating the quality, extent, and rapidity of his learning.

The student analyzes his test and evaluates his progress, selecting appropriate instructional activities to help him learn concepts or skills he has not acquired.[a]

The student discusses his instructional requirements with his teacher, cooperates in evaluation of his present attainments and future needs.[a]

Level E

After completing and correcting a unit mastery test and given a list that relates questions on the test to topics considered in the unit, the student identifies those topics he or she has not learned satisfactorily.

Upon completion of the analysis of a unit mastery test, the student uses activities related to the topics not learned satisfactorily to design a remedial learning plan and discusses this plan with the teacher.

Level D

As a part of participation in an Alternative Pathway unit, the student in a Student-Teacher Conference assesses his or her accomplishments in the unit and suggests ways in which his or her work in the unit might have been improved.

Level C

After correcting checkup he has taken or after obtaining the results of a unit mastery test or activity, the student identifies those topics he has not learned satisfactorily and participates with the teacher in making a decision about whether or not remedial instruction is necessary and, if so, what form of remedial instruction he will take.

In a unit where a mastery test or activity is available, the student participates with the teacher in making a decision about when he is ready to attempt the test or activity.

After completing a checkup and obtaining a key for it, the student compares his completed checkup with the key, assigns point values to correct answers, and calculates his total points for the checkup.

In a unit with one or more integrating checkups (i.e., a checkup which ties together the content of several lessons, readings, and/or other activities), the student participates with the teacher in making a decision about when he is ready to work on a checkup.

After completing a Placement Test and obtaining a key for it, the student compares his answers with the key, assigns point values to correct answers, and calculates his total points for the Placement Test.

While taking a Placement Test (taken before beginning study in a unit), the student elects to answer any question for which he knows the answer or omits any question for which he does not know the answer.

Level B

The student corrects his work on selected booklet pages using a key.

Level A

After completing a self-check page (identified by a key around page number) in a lesson booklet, the student compares his answers with those on a model page which is completed correctly.

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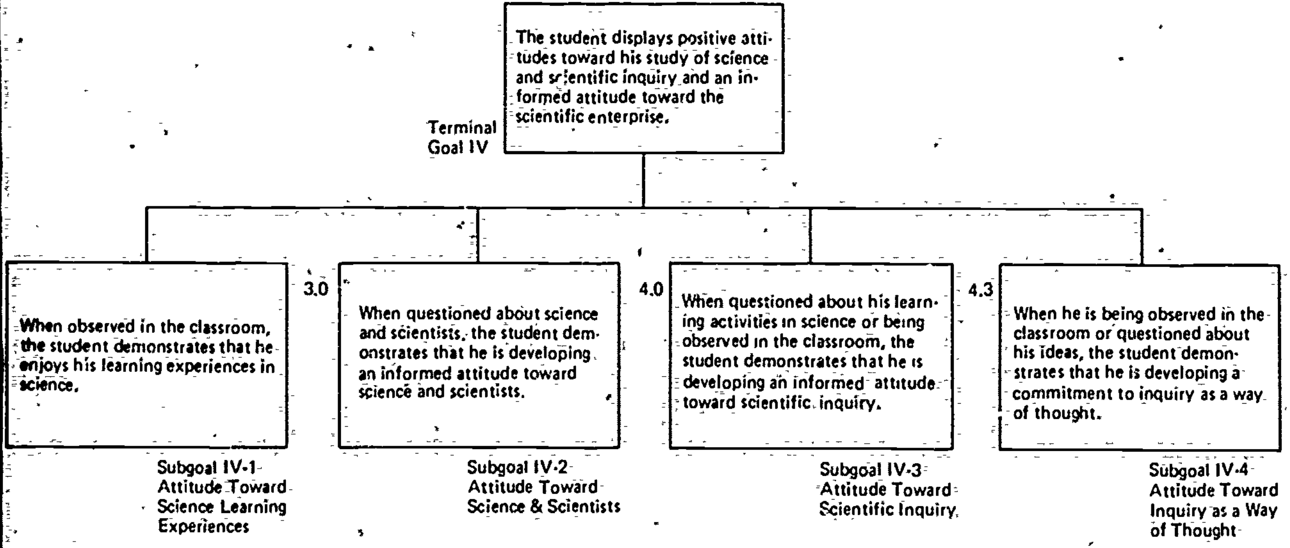
[a] Objectives added to those identified by developers.

CHART 4

Curriculum Analysis of Individualized Science: Subgoals of the Affective Goal



Terminal Goal IV

The student displays positive attitudes toward his study of science and scientific inquiry and an informed attitude toward the scientific enterprise.

When observed in the classroom, the student demonstrates that he enjoys his learning experiences in science.

Subgoal IV-1 Attitude Toward Science Learning Experiences

3.0

When questioned about science and scientists, the student demonstrates that he is developing an informed attitude toward science and scientists.

Subgoal IV-2 Attitude Toward Science & Scientists

4.0

When questioned about his learning activities in science or being observed in the classroom, the student demonstrates that he is developing an informed attitude toward scientific inquiry.

Subgoal IV-3 Attitude Toward Scientific Inquiry

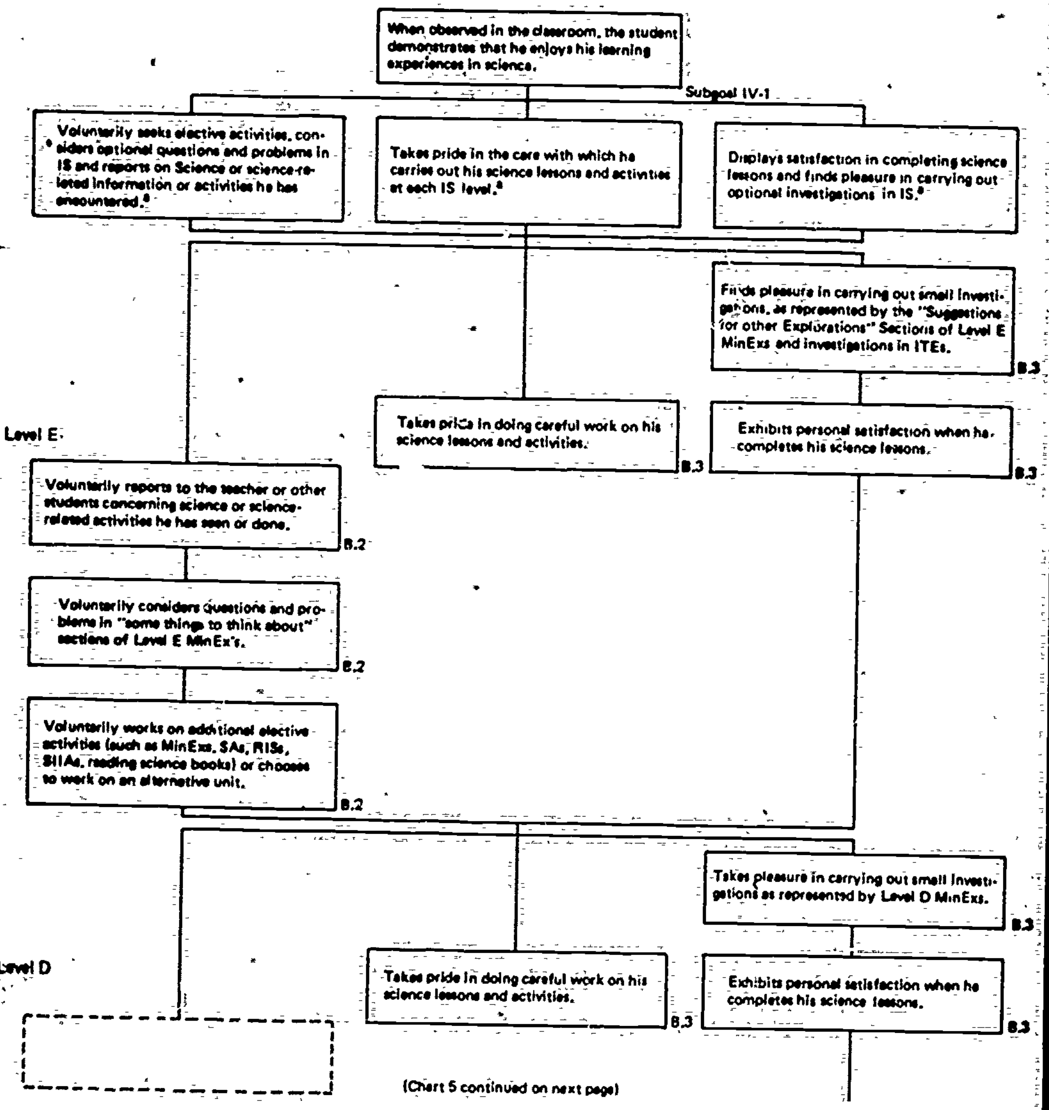
4.3

When he is being observed in the classroom or questioned about his ideas, the student demonstrates that he is developing a commitment to inquiry as a way of thought.

Subgoal IV-4 Attitude Toward Inquiry as a Way of Thought

CHART 5

Curriculum Analysis of Individualized Science: Hierarchy of the Affective Subgoal IV-1— Attitude Toward Science Learning Experiences


When observed in the classroom, the student demonstrates that he enjoys his learning experiences in science.

Voluntarily seeks elective activities, considers optional questions and problems in IS and reports on Science or science-related information or activities he has encountered.[a]

Takes pride in the care with which he carries out his science lessons and activities at each IS level.[a]

Displays satisfaction in completing science lessons and finds pleasure in carrying out optional investigations in IS.[a]

Finds pleasure in carrying out small investigations, as represented by the "Suggestions for other Explorations" Sections of Level E MinExs and investigations in ITEs.

Takes pride in doing careful work on his science lessons and activities.

Exhibits personal satisfaction when he completes his science lessons.

Voluntarily reports to the teacher or other students concerning science or science-related activities he has seen or done.

Voluntarily considers questions and problems in "some things to think about" sections of Level E MinEx's.

Voluntarily works on additional elective activities (such as MinExs, SAs, RISs, SIIAs, reading science books) or chooses to work on an alternative unit.

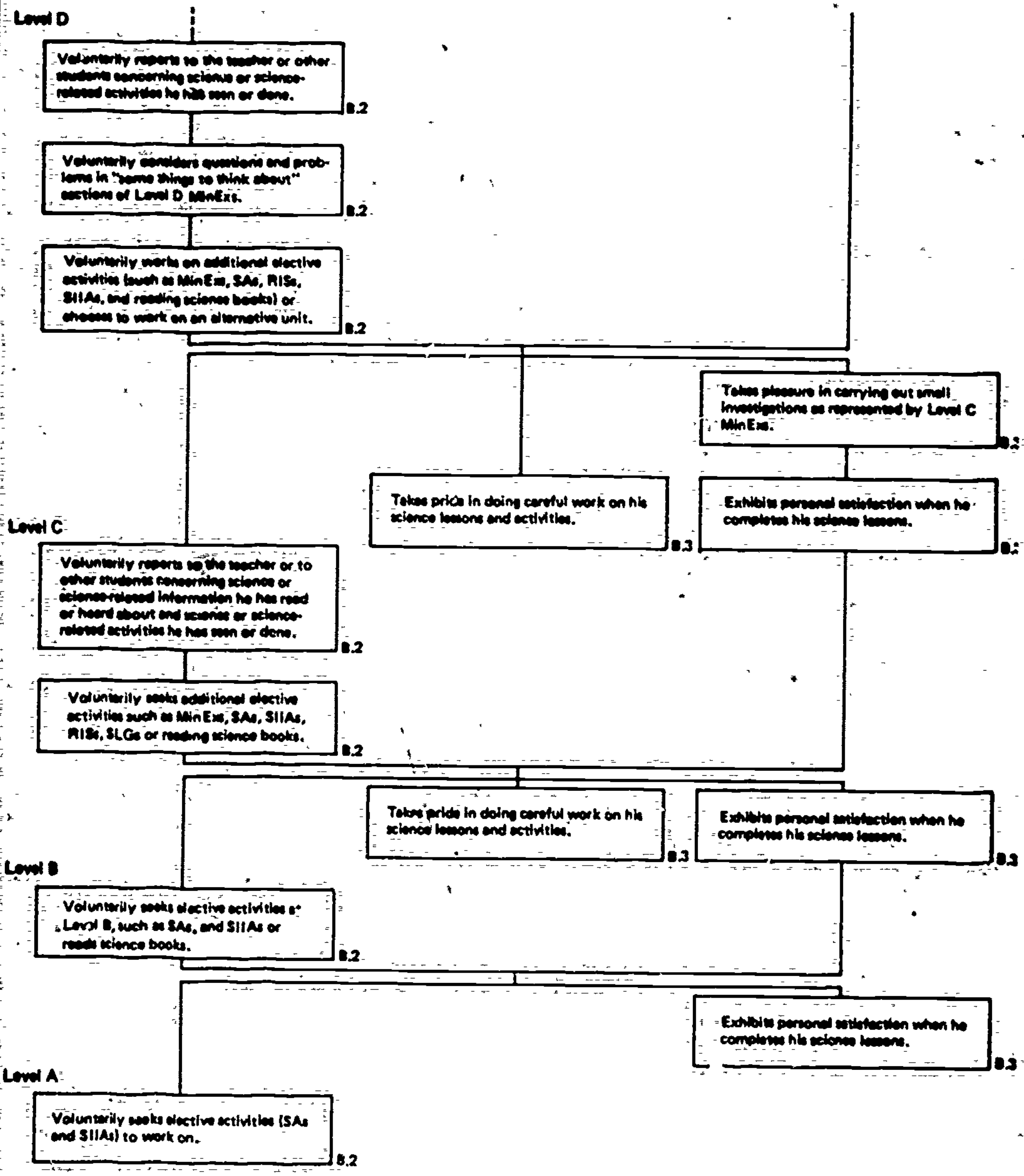
Takes pleasure in carrying out small investigations as represented by Level D MinExs.

Takes pride in doing careful work on his science lessons and activities.

Exhibits personal satisfaction when he completes his science lessons.

(Chart 5 continued on next page)

Chart 5 (Cont'd)



Level D

Voluntarily reports to the teacher or other students concerning science or science-related activities he has seen or done. B.2

Voluntarily considers questions and problems in "some things to think about" sections of Level D MinExs. B.2

Voluntarily works on additional elective activities (such as MinExs, SAs, RISs, SIIAs, and reading science books) or chooses to work on an alternative unit. B.2

Takes pleasure in carrying out small investigations as represented by Level C MinExs. B.3

Takes pride in doing careful work on his science lessons and activities. B.3

Exhibits personal satisfaction when he completes his science lessons. B.3

Level C

Voluntarily reports to the teacher or to other students concerning science or science-related information he has read or heard about and science or science-related activities he has seen or done. B.2

Voluntarily seeks additional elective activities such as MinExs, SAs, SIIAs, RISs, SLGs or reading science books. B.2

Takes pride in doing careful work on his science lessons and activities. B.3

Exhibits personal satisfaction when he completes his science lessons. B.3

Level B

Voluntarily seeks elective activities at Level B, such as SAs, and SIIAs or reads science books. B.2

Exhibits personal satisfaction when he completes his science lessons. B.3

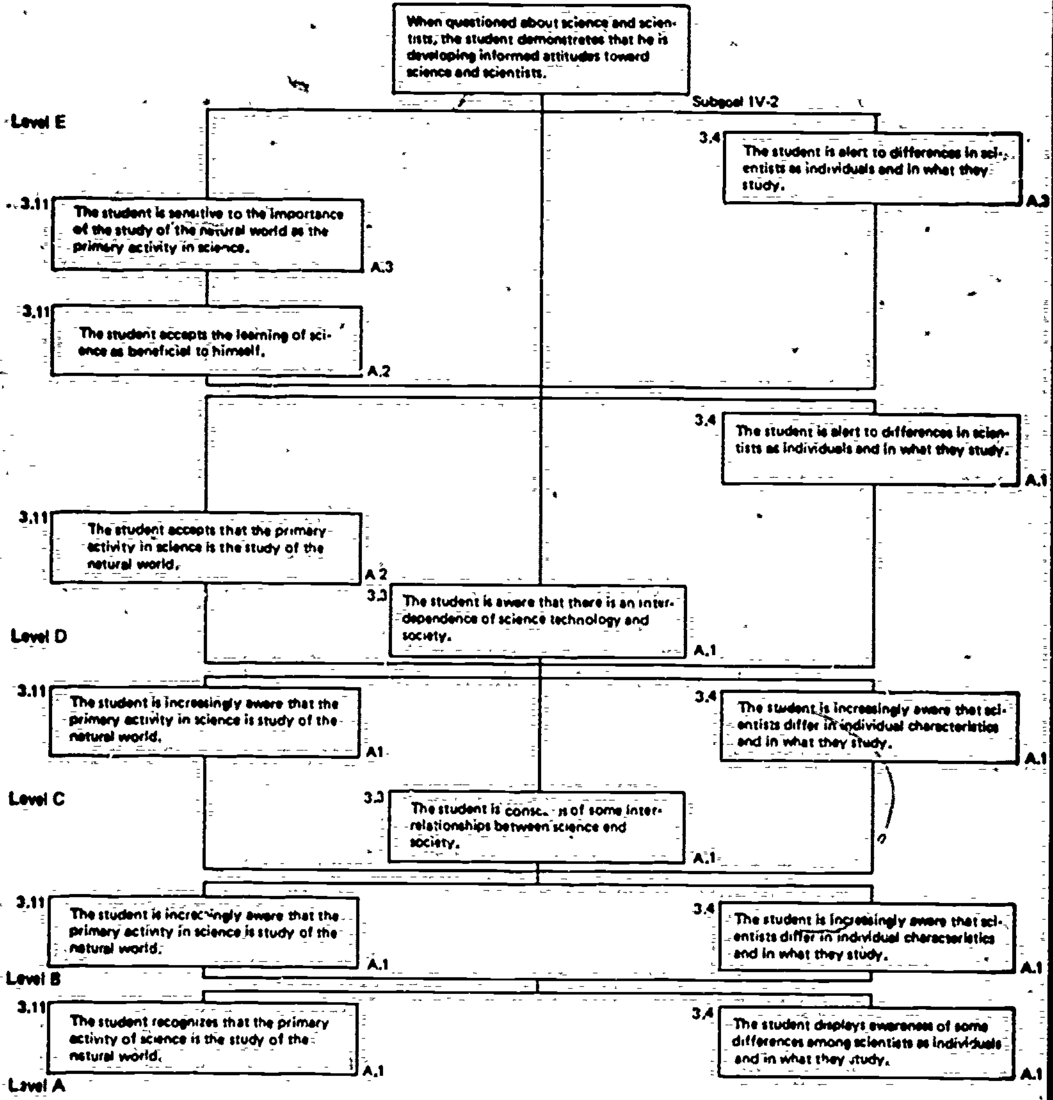
Level A

Voluntarily seeks elective activities (SAs and SIIAs) to work on. B.2

[a] Objective added to those identified by developers.

CHART 6

Curriculum Analysis of Individualized Science: Hierarchy of the Affective Subgoal IV-2—Attitude Toward Science and Scientists



When questioned about science and scientists, the student demonstrates that he is developing informed attitudes toward science and scientists.

Subgoal IV-2

Level E

3.4 The student is alert to differences in scientists as individuals and in what they study. A.3

3.11 The student is sensitive to the importance of the study of the natural world as the primary activity in science. A.3

3.11 The student accepts the learning of science as beneficial to himself. A.2

Level D

3.4 The student is alert to differences in scientists as individuals and in what they study. A.1

3.11 The student accepts that the primary activity in science is the study of the natural world. A.2

3.3 The student is aware that there is an interdependence of science technology and society. A.1

Level C

3.11 The student is increasingly aware that the primary activity in science is study of the natural world. A1

3.4 The student is increasingly aware that scientists differ in individual characteristics and in what they study. A.1

3.3 The student is conscious of some interrelationships between science and society. A.1

Level B

3.11 The student is increasingly aware that the primary activity in science is study of the natural world. A.1

3.4 The student is increasingly aware that scientists differ in individual characteristics and in what they study. A.1

Level A

3.11 The student recognizes that the primary activity of science is the study of the natural world. A.1

3.4 The student displays awareness of some differences among scientists as individuals and in what they study. A.1

CHART 7

Curriculum Analysis of Individualized Science: Hierarchy of the Affective Subgoal IV-3 – Attitude Toward Scientific Inquiry

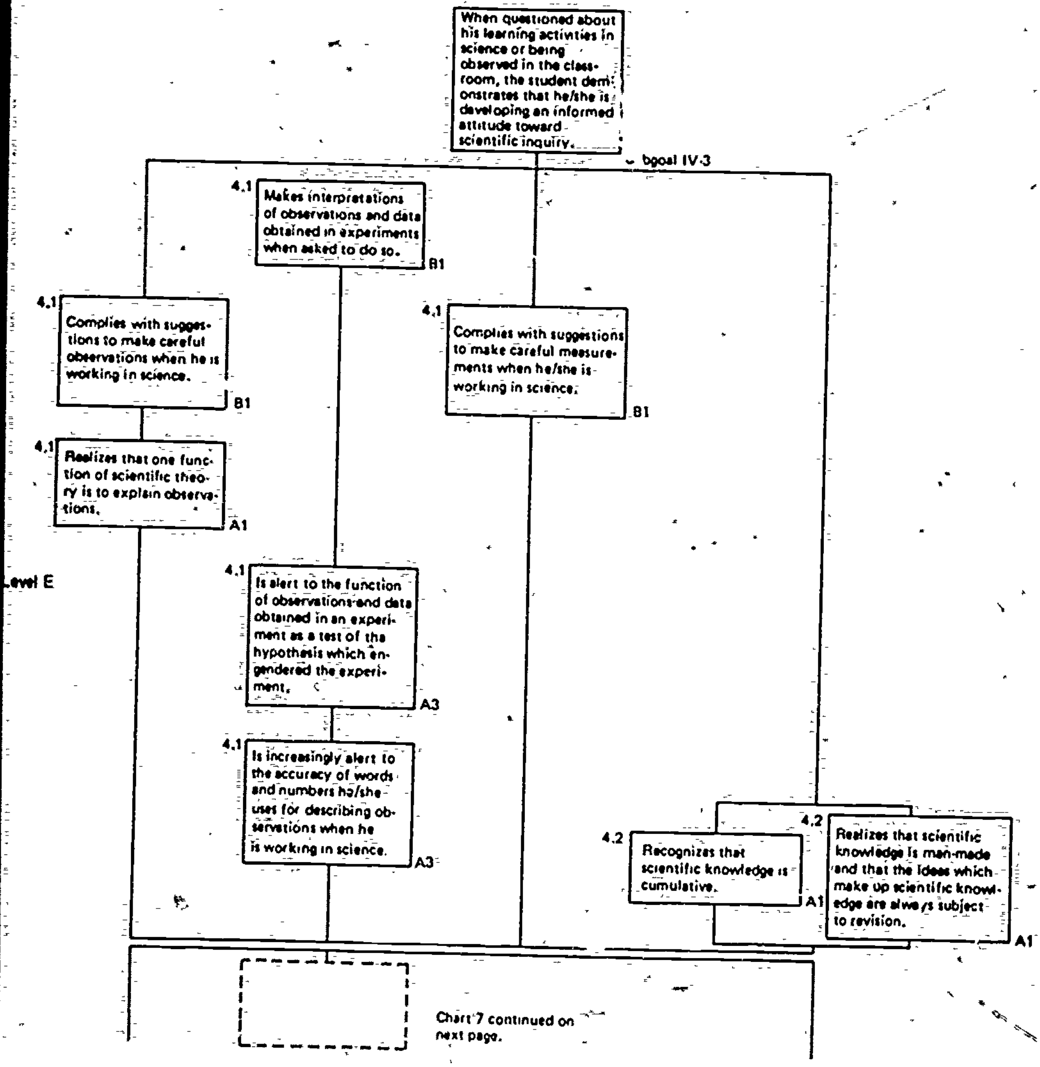
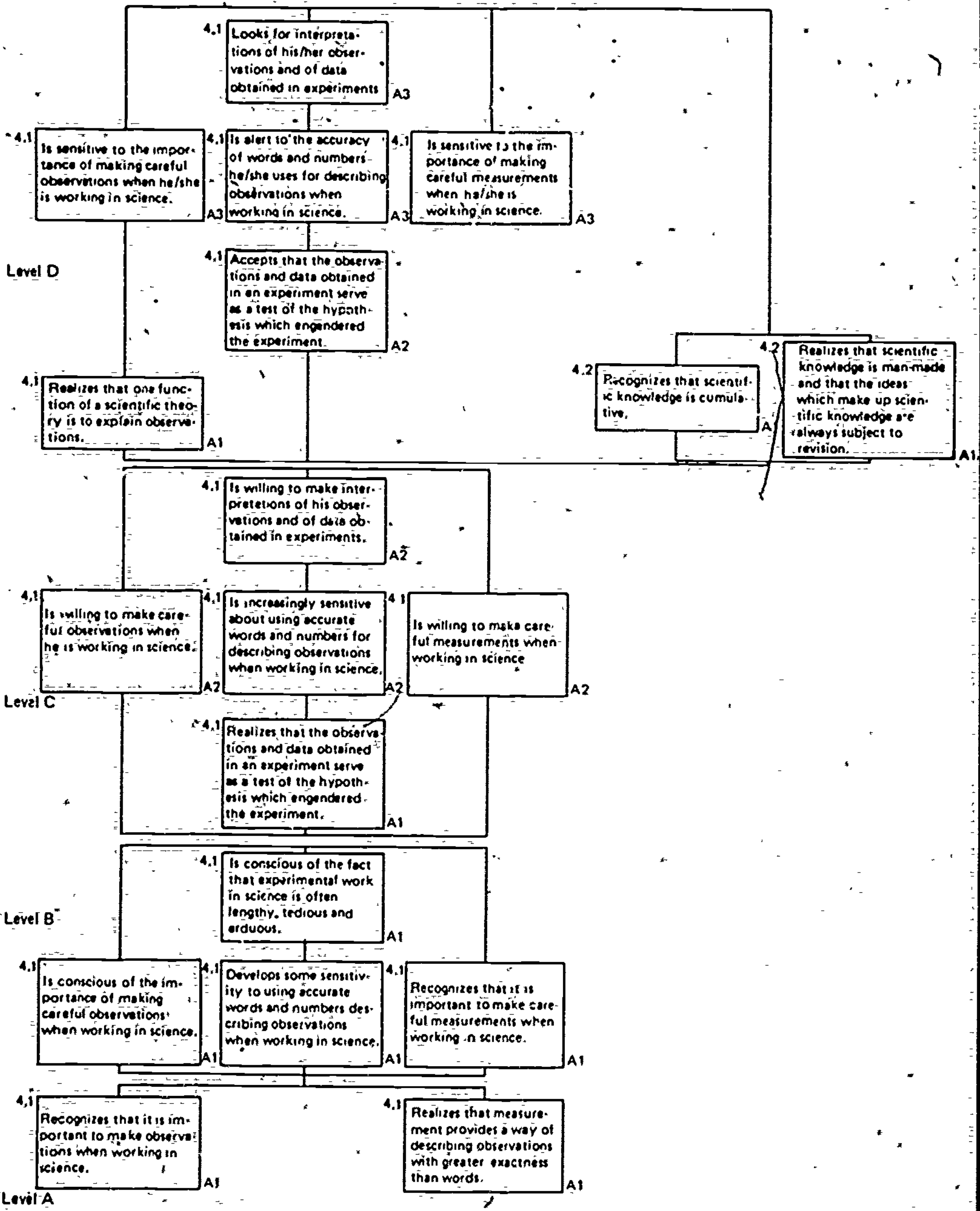
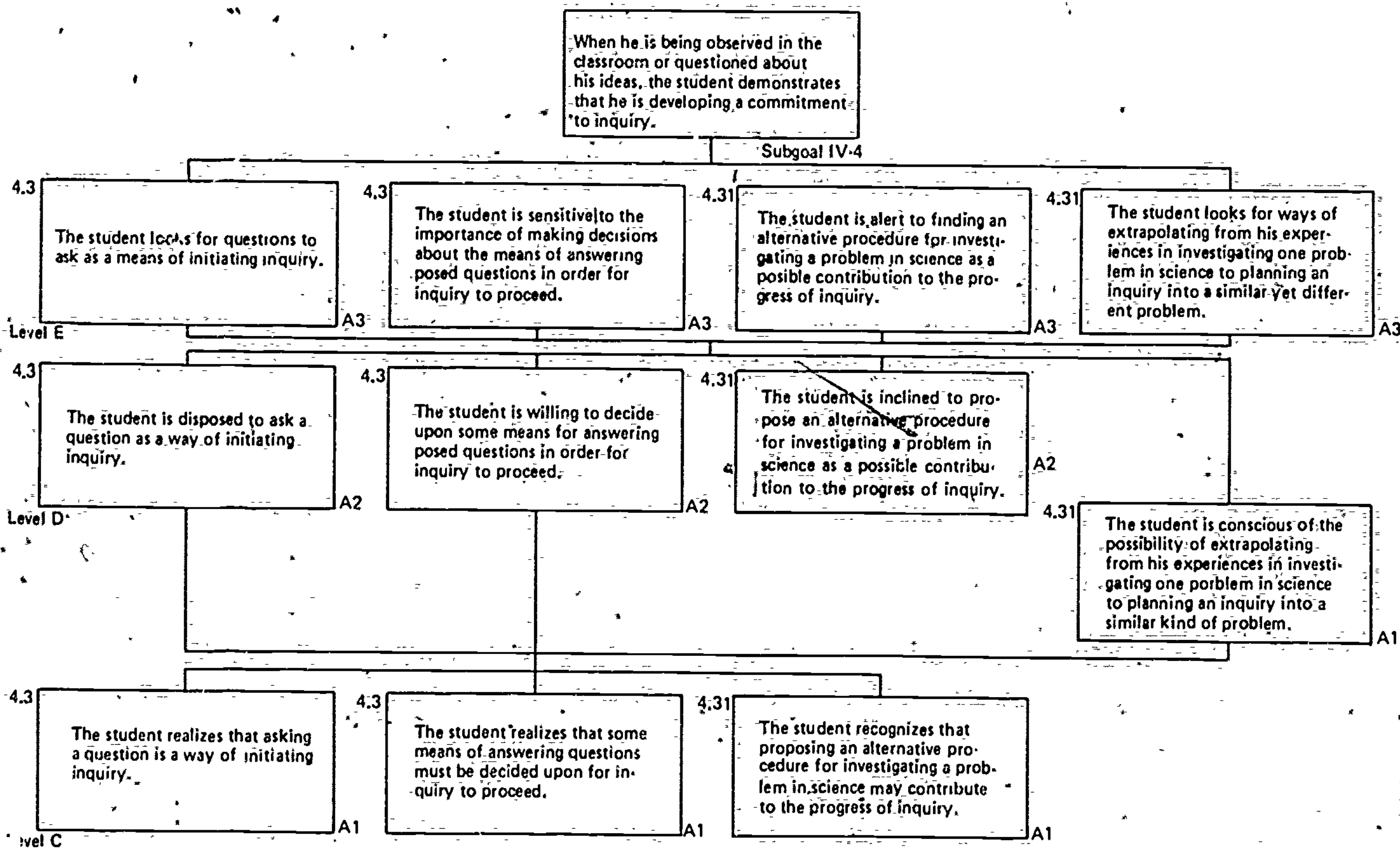


Chart 7 (Cont'd)



Curriculum Analysis of Individualized Science: Hierarchy of the Affective Subgoal IV-4 – Attitude Toward Inquiry as a Way of Thought



When he is being observed in the classroom or questioned about his ideas, the student demonstrates that he is developing a commitment to inquiry.

Subgoal IV-4

Level E

4.3 The student looks for questions to ask as a means of initiating inquiry. A3

4.3 The student is sensitive to the importance of making decisions about the means of answering posed questions in order for inquiry to proceed. A3

4.31 The student is alert to finding an alternative procedure for investigating a problem in science as a posible contribution to the progress of inquiry. A3

4.31 The student looks for ways of extrapolating from his experiences in investigating one problem in science to planning an inquiry into a similar yet different problem. A3

Level D

4.3 The student is disposed to ask a question as a way of initiating inquiry. A2

4.3 The student is willing to decide upon some means for answering posed questions in order for inquiry to proceed. A2

4.31 The student is inclined to propose an alternative procedure for investigating a problem in science as a possible contribution to the progress of inquiry. A2

4.31 The student is conscious of the possibility of extrapolating from his experiences in investigating one porblem in science to planning an inquiry into a similar kind of problem. A1

Level C

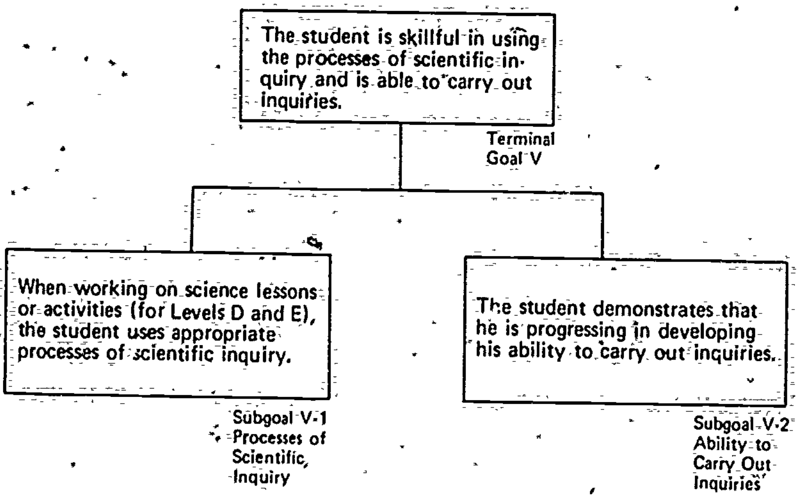
4.3 The student realizes that asking a question is a way of initiating inquiry. A1

4.3 The student realizes that some means of answering questions must be decided upon for inquiry to proceed. A1

4.31 The student recognizes that proposing an alternative procedure for investigating a problem in science may contribute to the progress of inquiry. A1

CHART 9

Curriculum Analysis of Individualized Science. Subgoals of the Inquiry Goal



The student is skillful in using the processes of scientific inquiry and is able to carry out inquiries.

Terminal Goal V

When working on science lessons or activities (for Levels D and E), the student uses appropriate processes of scientific inquiry.

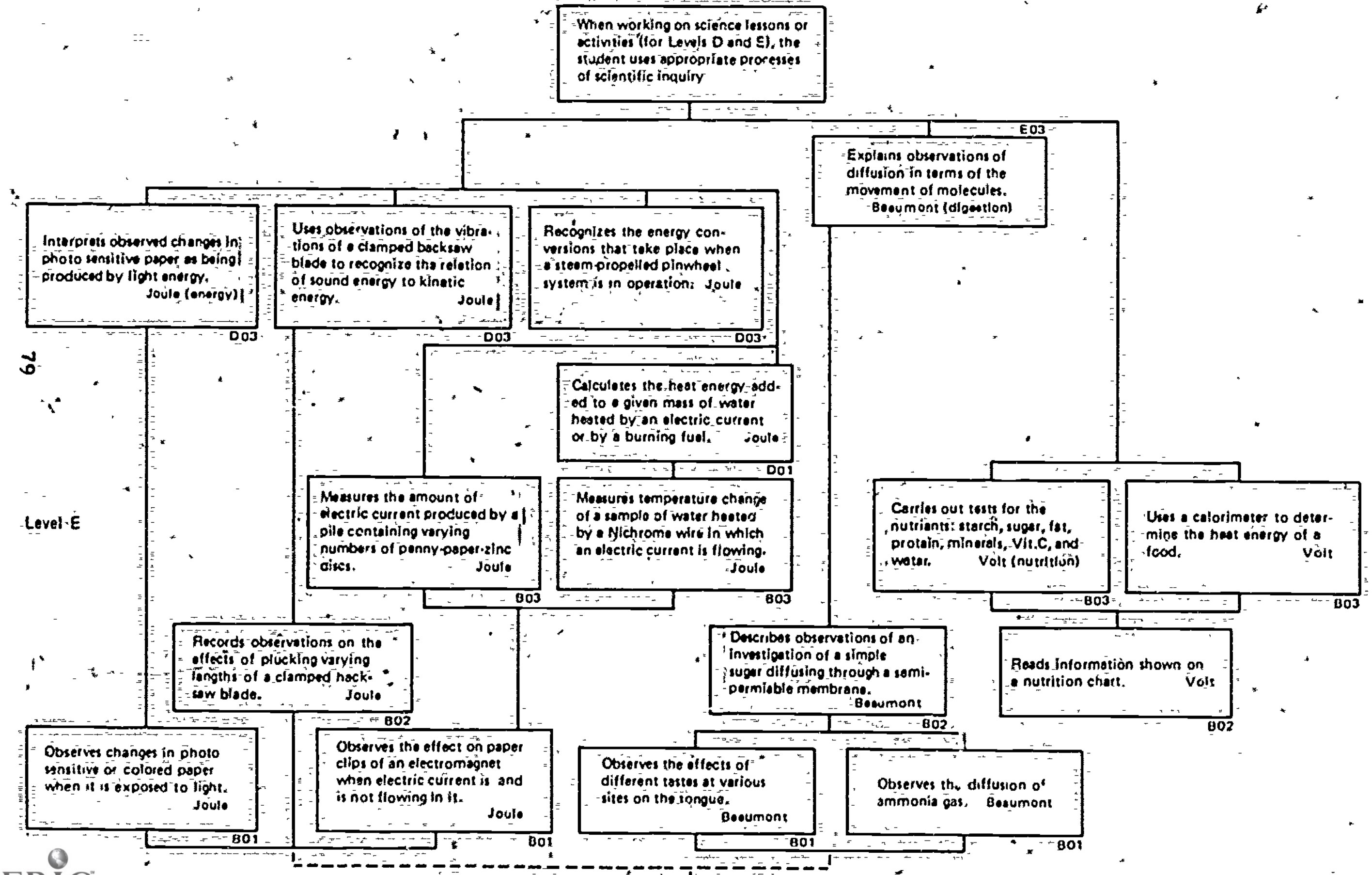
Subgoal V-1
Processes of Scientific Inquiry

The student demonstrates that he is progressing in developing his ability to carry out inquiries.

Subgoal V-2
Ability to Carry Out Inquiries

CHART 10

Curriculum Analysis of Individualized Science: Hierarchy of the Inquiry Subgoal V-1 — Use of Appropriate Processes of Scientific Inquiry



When working on science lessons or activities (for Levels D and E), the student uses appropriate processes of scientific inquiry

Explains observations of diffusion in terms of the movement of molecules. Beaumont (digestion)

Interprets observed changes in photo sensitive paper as being produced by light energy. Joule (energy)

Uses observations of the vibrations of a clamped backsaw blade to recognize the relation of sound energy to kinetic energy. Joule

Recognizes the energy conversions that take place when a steam-propelled pinwheel system is in operation. Joule

Calculates the heat energy added to a given mass of water heated by an electric current or by a burning fuel. Joule

Measures the amount of electric current produced by a pile containing varying numbers of penny-paper-zinc discs. Joule

Measures temperature change of a sample of water heated by a Nichrome wire in which an electric current is flowing. Joule

Carries out tests for the nutrients: starch, sugar, fat, protein, minerals, Vit.C, and water. Volt (nutrition)

Uses a calorimeter to determine the heat energy of a food. Volt

Records observations on the effects of plucking varying lengths of a clamped hacksaw blade. Joule

Describes observations of an investigation of a simple sugar diffusing through a semi-permeable membrane. Beaumont

Reads information shown on a nutrition chart. Volt

Observes changes in photo sensitive or colored paper when it is exposed to light. Joule

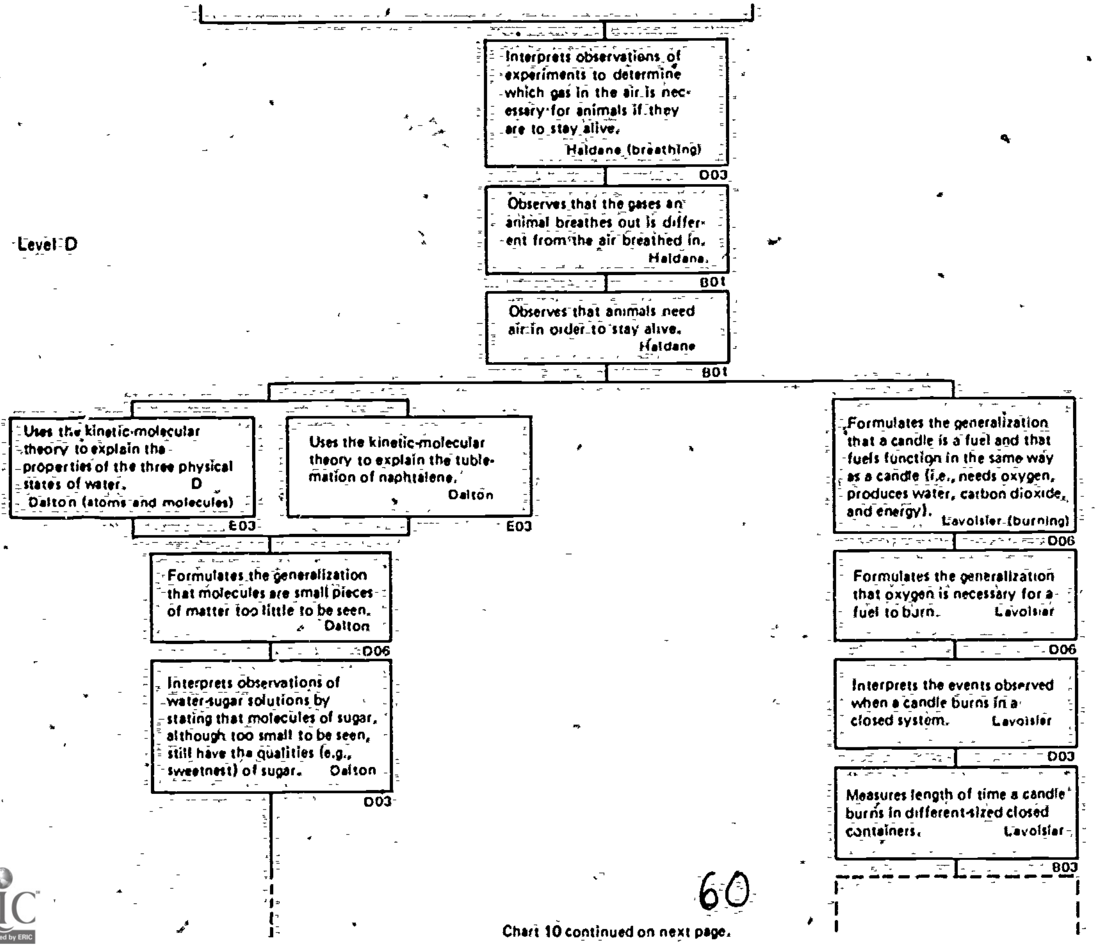
Observes the effect on paper clips of an electromagnet when electric current is and is not flowing in it. Joule

Observes the effects of different tastes at various sites on the tongue. Beaumont

Observes the diffusion of ammonia gas. Beaumont

Chart 10 continued on next page.

Chart 10 (Cont'd)



Interprets observations of experiments to determine which gas in the air is necessary for animals if they are to stay alive. Haldane (breathing)

Observes that the gases an animal breathes out is different from the air breathed in. Haldane.

Observes that animals need air in order to stay alive. Haldane

Uses the kinetic-molecular theory to explain the properties of the three physical states of water. D Dalton (atoms and molecules)

Uses the kinetic-molecular theory to explain the sublimation of naphtalene. Dalton

Formulates the generalization that molecules are small pieces of matter too little to be seen. Dalton

Interprets observations of water-sugar solutions by stating that molecules of sugar, although too small to be seen, still have the qualities (e.g., sweetness) of sugar. Dalton

Formulates the generalization that a candle is a fuel and that fuels function in the same way as a candle (i.e., needs oxygen, produces water, carbon dioxide, and energy). Lavoisier (burning)

Formulates the generalization that oxygen is necessary for a fuel to burn. Lavoisier

Interprets the events observed when a candle burns in a closed system. Lavoisier

Measures length of time a candle burns in different-sized closed containers. Lavoisier

Chart 10 continued on next page.

Chart 10 (Cont'd)

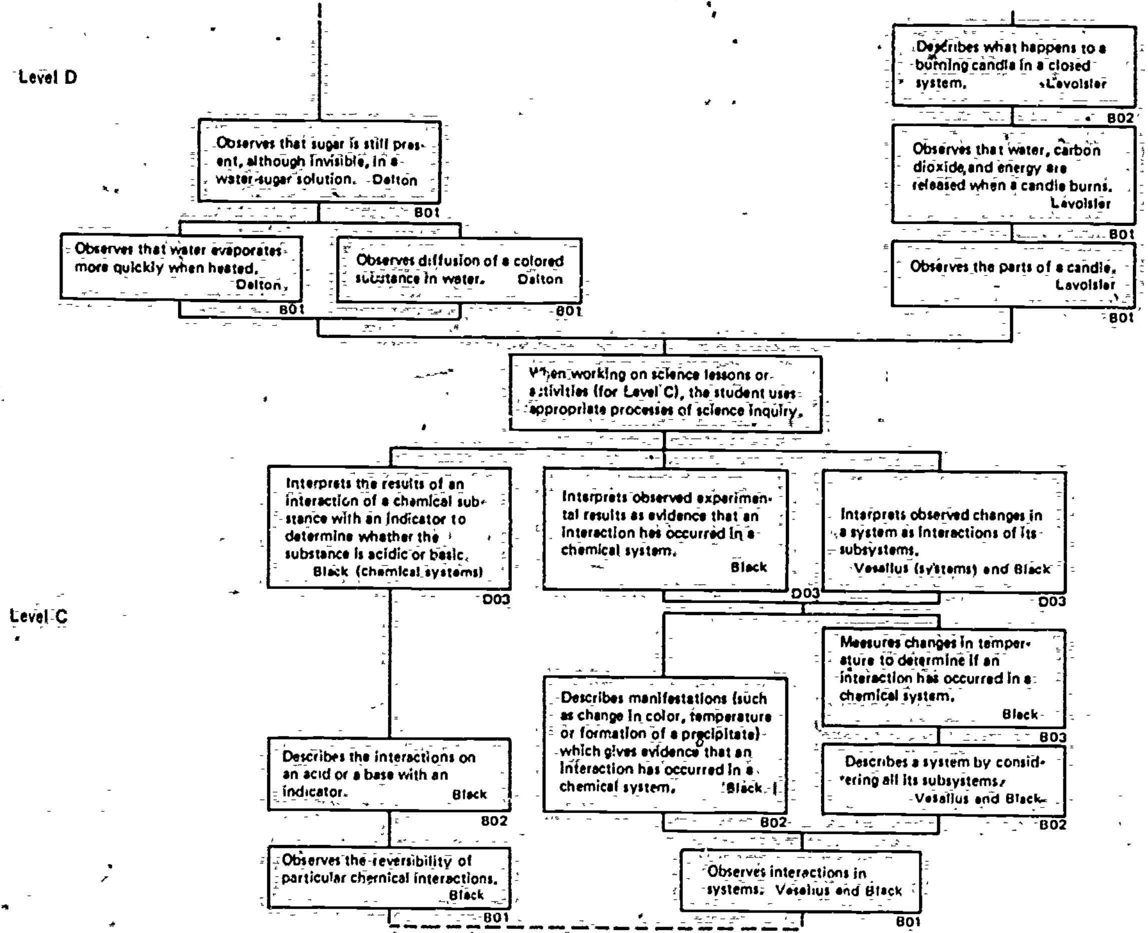


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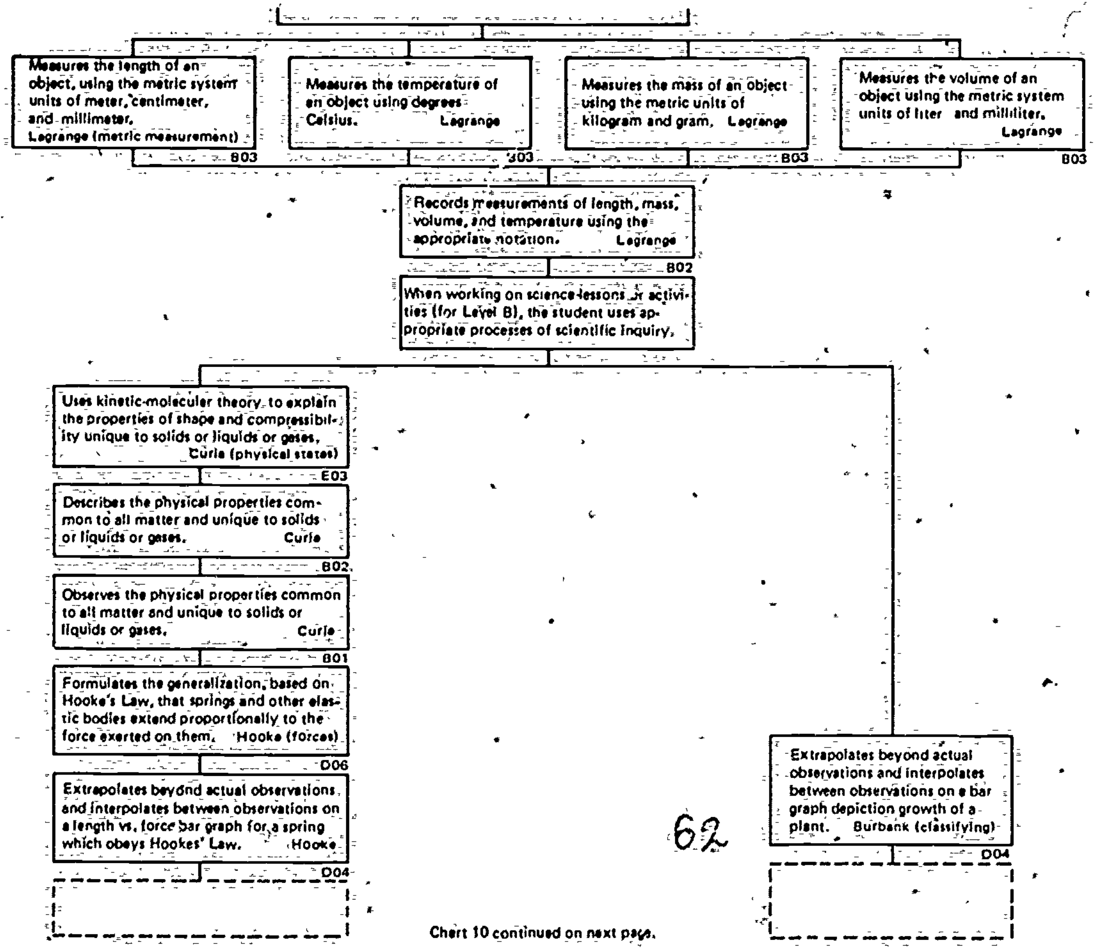
Chart 10 (Cont'd)



Measures the length of an object, using the metric system units of meter, centimeter, and millimeter. Lagrange (metric measurement) B03

Measures the temperature of an object using degrees Celsius. Lagrange B03

Measures the mass of an object using the metric units of kilogram and gram. Lagrange B03

Measures the volume of an object using the metric system units of liter and milliliter. Lagrange B03

Records measurements of length, mass, volume, and temperature using the appropriate notation. Lagrange B02

When working on science lessons or activities (for Level B), the student uses appropriate processes of scientific inquiry.

Level B

Uses kinetic-molecular theory to explain the properties of shape and compressibility unique to solids or liquids or gases. Curie (physical states) E03

Describes the physical properties common to all matter and unique to solids or liquids or gases. Curie B02

Observes the physical properties common to all matter and unique to solids or liquids or gases. Curie B01

Formulates the generalization, based on Hooke's Law, that springs and other elastic bodies extend proportionally to the force exerted on them. Hooke (forces) D06

Extrapolates beyond actual observations and interpolates between observations on a length vs. force bar graph for a spring which obeys Hookes' Law. Hooke D04

Extrapolates beyond actual observations and interpolates between observations on a bar graph depiction growth of a plant. Burbank (classifying) D04

62

Chart 10 continued on next page.

Chart 10 (Cont'd).

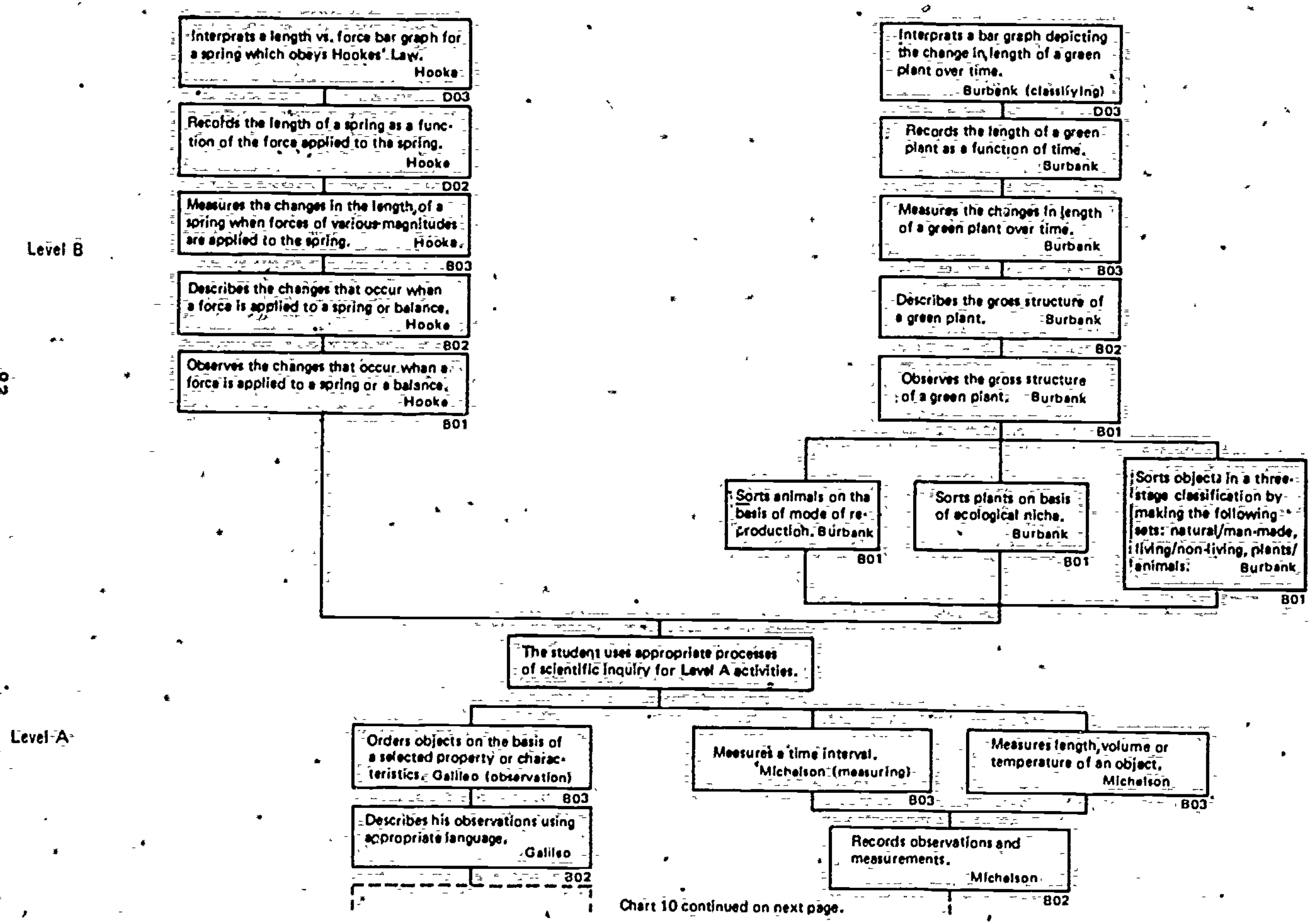


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Chart 10 (Cont'd)

Level A

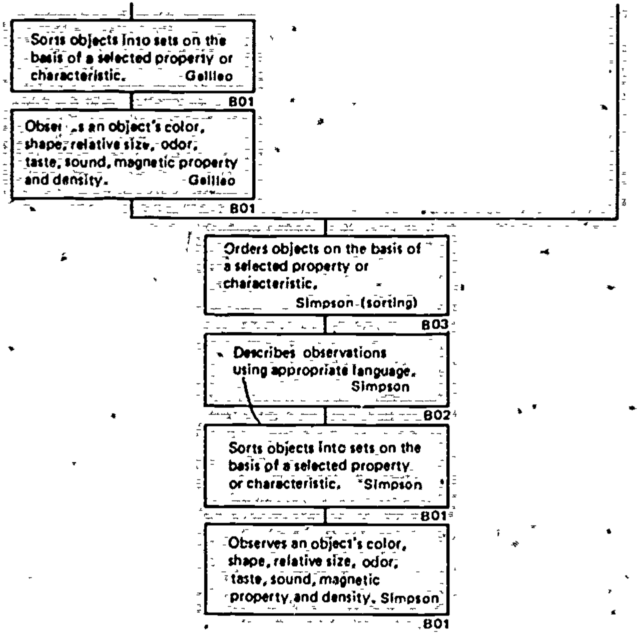

CHART 11

Curriculum Analysis of Individualized Science: Hierarchy of the Inquiry Subgoal V-2– Developing Ability to Carry Out Inquiries

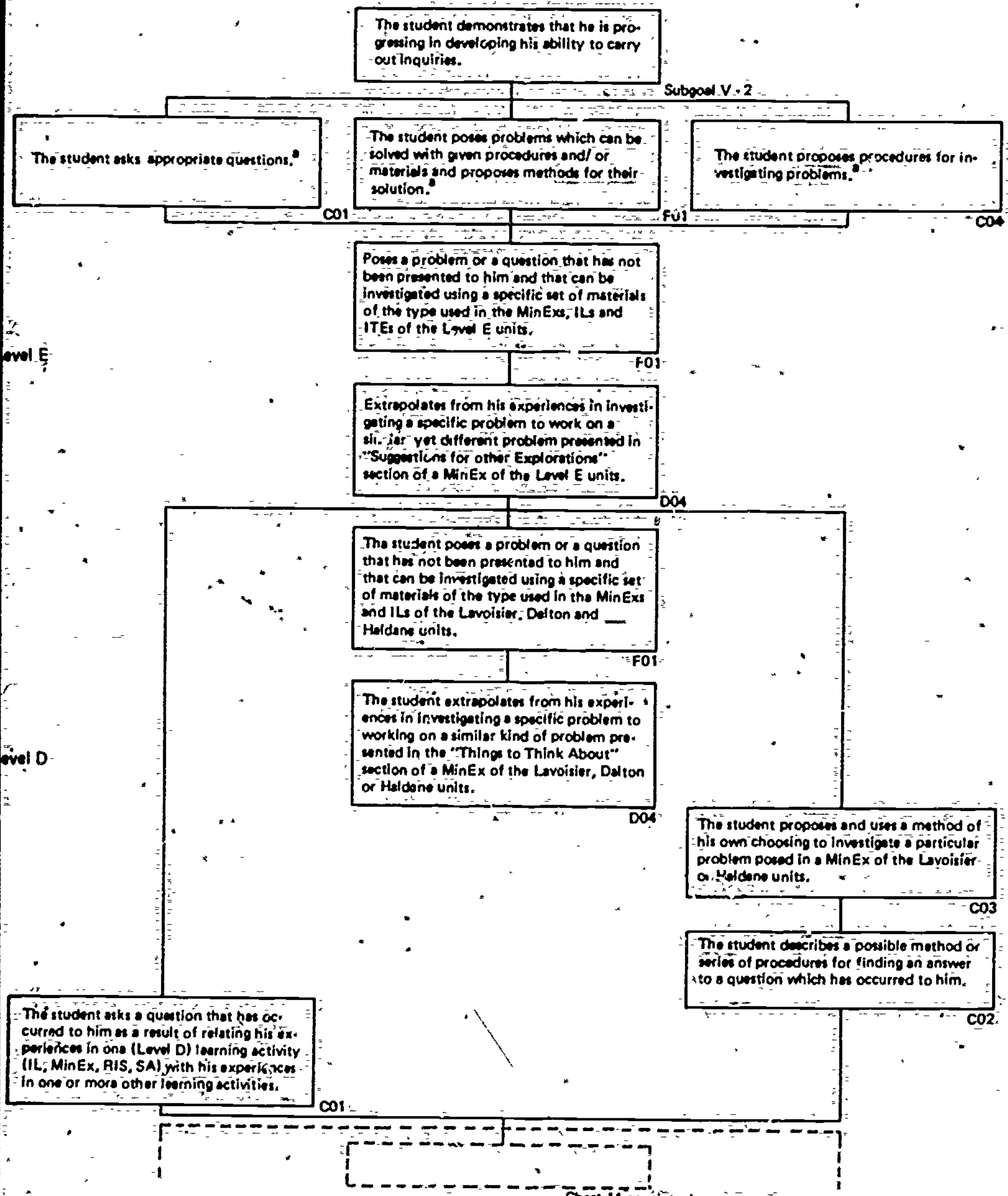

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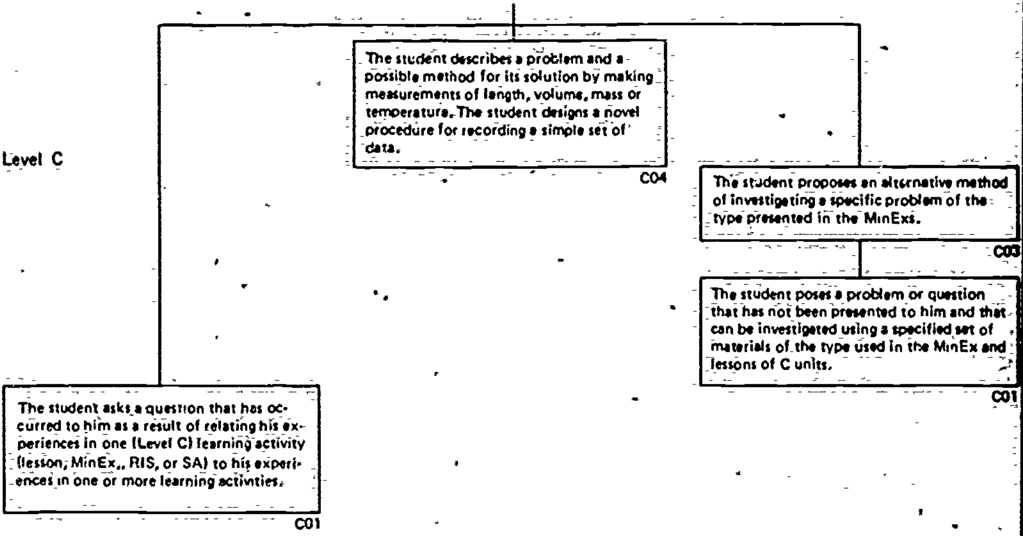
Chart 11 (Cont'd)



Level C

The student describes a problem and a possible method for its solution by making measurements of length, volume, mass or temperature. The student designs a novel procedure for recording a simple set of data.

C04

The student proposes an alternative method of investigating a specific problem of the type presented in the MinExs.

C03

The student poses a problem or question that has not been presented to him and that can be investigated using a specified set of materials of the type used in the MinEx and lessons of C units.

C01

The student asks a question that has occurred to him as a result of relating his experiences in one (Level C) learning activity (lesson, MinEx., RIS, or SA) to his experiences in one or more learning activities.

C01

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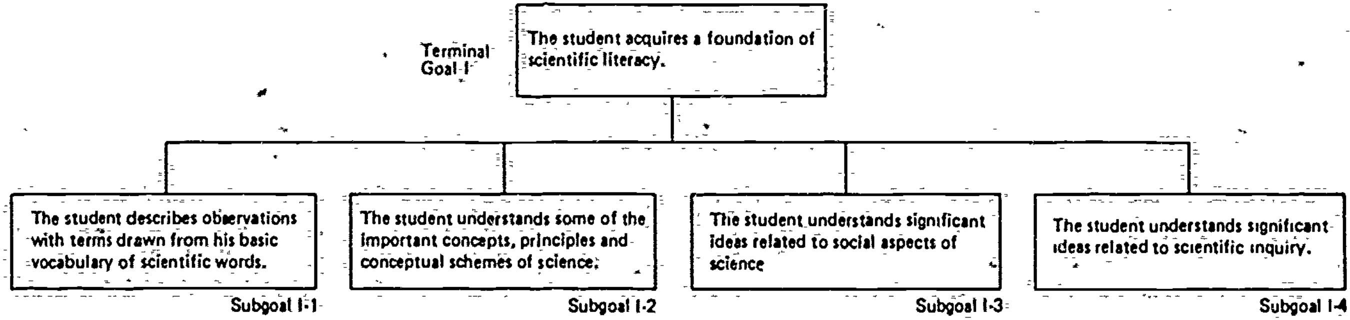
[a] Objective added to those identified by developers.

CHART 12

Curriculum Analysis of Individualized Science: Subgoals of the Scientific Literacy Goal



Terminal Goal I

The student acquires a foundation of scientific literacy.

The student describes observations with terms drawn from his basic vocabulary of scientific words.

Subgoal I-1

The student understands some of the important concepts, principles and conceptual schemes of science.

Subgoal I-2

The student understands significant ideas related to social aspects of science

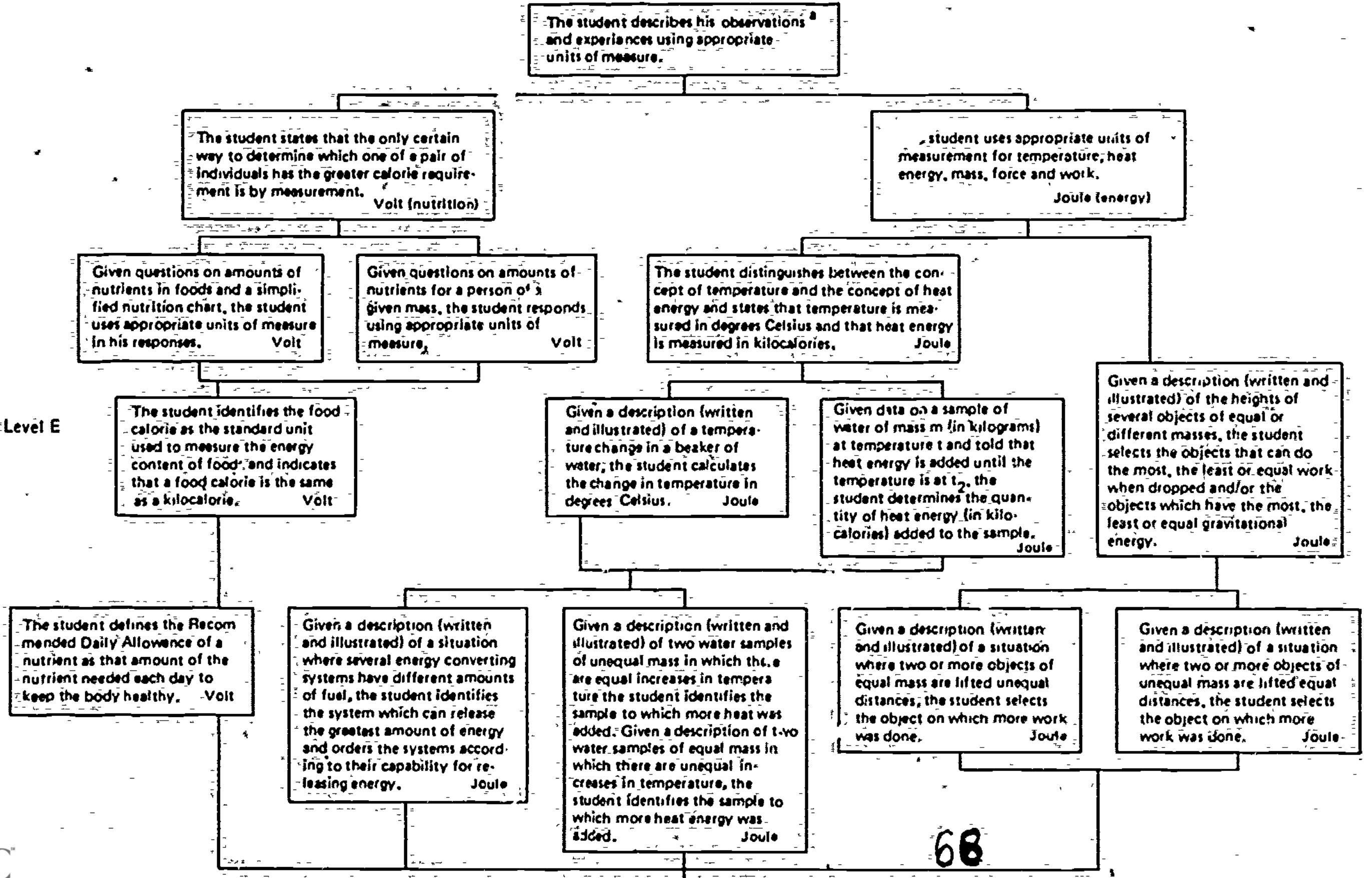
Subgoal I-3

The student understands significant ideas related to scientific inquiry.

Subgoal I-4

CHART 13

Curriculum Analysis of Individualized Science: Illustrative Hierarchy of Scientific Terminology Subgoal I-1 – Measurement Terminology



The student describes his observations[a] and experiences using appropriate units of measure.

The student states that the only certain way to determine which one of a pair of individuals has the greater calorie requirement is by measurement. Volt (nutrition)

The student uses appropriate units of measurement for temperature, heat energy, mass, force and work. Joule (energy)

Given questions on amounts of nutrients in foods and a simplified nutrition chart, the student uses appropriate units of measure in his responses. Volt

Given questions on amounts of nutrients for a person of a given mass, the student responds using appropriate units of measure. Volt

The student distinguishes between the concept of temperature and the concept of heat energy and states that temperature is measured in degrees Celsius and that heat energy is measured in kilocalories. Joule

Given a description (written and illustrated) of the heights of several objects of equal or different masses, the student selects the objects that can do the most, the least or equal work when dropped and/or the objects which have the most, the least or equal gravitational energy. Joule

Level E

The student identifies the food calorie as the standard unit used to measure the energy content of food, and indicates that a food calorie is the same as a kilocalorie. Volt

Given a description (written and illustrated) of a temperature change in a beaker of water, the student calculates the change in temperature in degrees Celsius. Joule

Given data on a sample of water of mass m (in kilograms) at temperature t and told that heat energy is added until the temperature is at t_2, the student determines the quantity of heat energy (in kilocalories) added to the sample. Joule

The student defines the Recommended Daily Allowance of a nutrient as that amount of the nutrient needed each day to keep the body healthy. Volt

Given a description (written and illustrated) of a situation where several energy converting systems have different amounts of fuel, the student identifies the system which can release the greatest amount of energy and orders the systems according to their capability for releasing energy. Joule

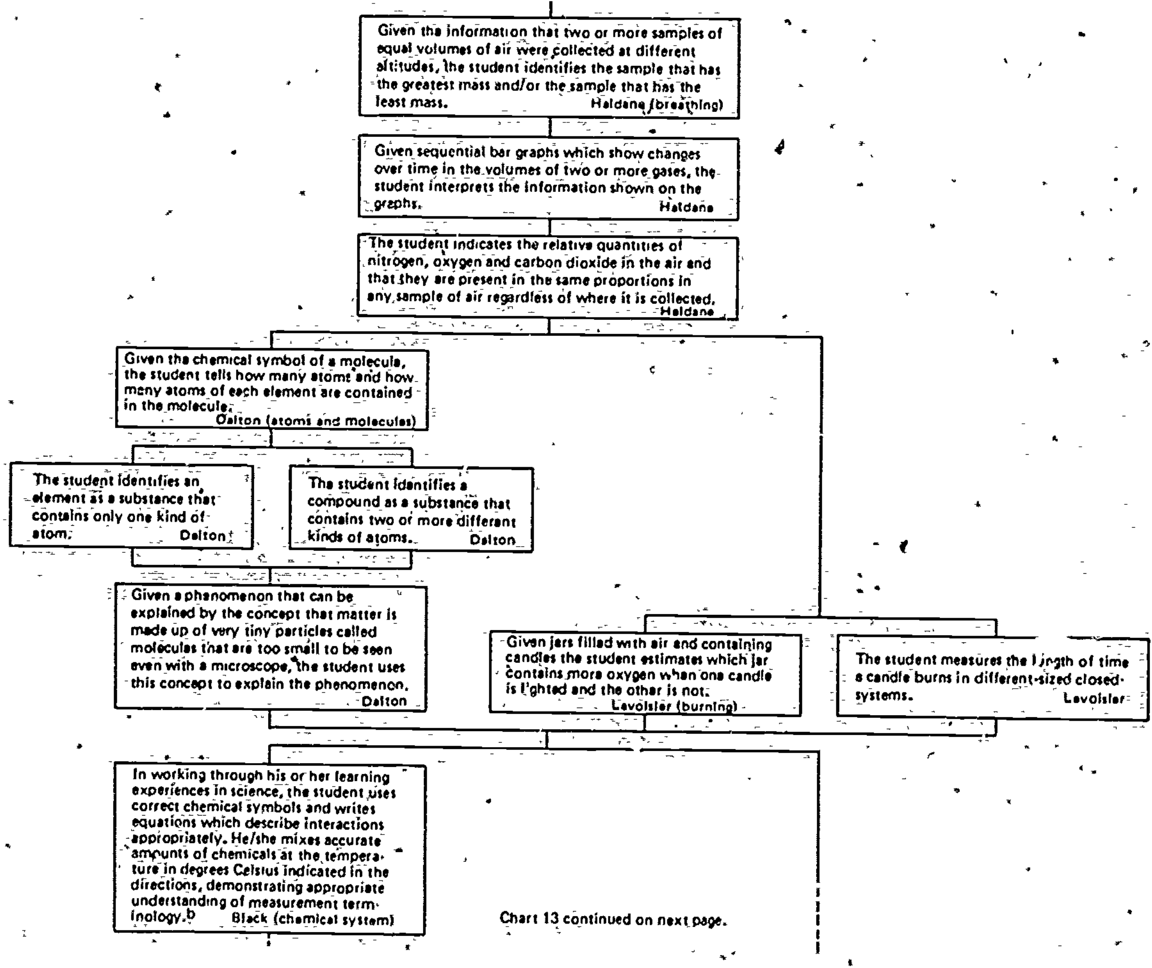
Given a description (written and illustrated) of two water samples of unequal mass in which there are equal increases in temperature the student identifies the sample to which more heat was added. Given a description of two water samples of equal mass in which there are unequal increases in temperature, the student identifies the sample to which more heat energy was added. Joule

Given a description (written and illustrated) of a situation where two or more objects of equal mass are lifted unequal distances, the student selects the object on which more work was done. Joule

Given a description (written and illustrated) of a situation where two or more objects of unequal mass are lifted equal distances, the student selects the object on which more work was done. Joule

Chart 13 continued on next page.

Chart 13 (Cont'd)



Given the information that two or more samples of equal volumes of air were collected at different altitudes, the student identifies the sample that has the greatest mass and/or the sample that has the least mass. Haldane (breathing)

Given sequential bar graphs which show changes over time in the volumes of two or more gases, the student interprets the information shown on the graphs. Haldane

Level D

The student indicates the relative quantities of nitrogen, oxygen and carbon dioxide in the air and that they are present in the same proportions in any sample of air regardless of where it is collected. Haldane

Given the chemical symbol of a molecule, the student tells how many atoms and how many atoms of each element are contained in the molecule. Dalton (atoms and molecules)

The student identifies an element as a substance that contains only one kind of atom. Dalton

The student identifies a compound as a substance that contains two or more different kinds of atoms. Dalton

Given a phenomenon that can be explained by the concept that matter is made up of very tiny particles called molecules that are too small to be seen even with a microscope, the student uses this concept to explain the phenomenon. Dalton

Given jars filled with air and containing candles the student estimates which jar contains more oxygen when one candle is lighted and the other is not. Lavoisier (burning)

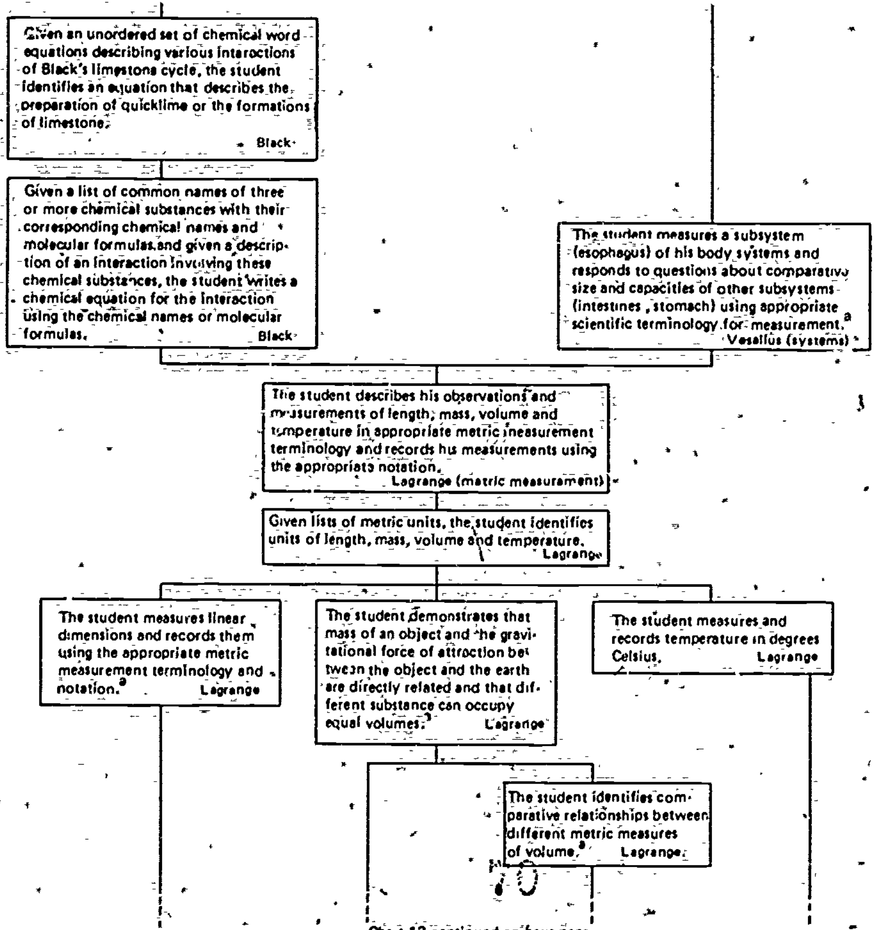
The student measures the length of time a candle burns in different-sized closed systems. Lavoisier

Level C

In working through his or her learning experiences in science, the student uses correct chemical symbols and writes equations which describe interactions appropriately. He/she mixes accurate amounts of chemicals at the temperature in degrees Celsius indicated in the directions, demonstrating appropriate understanding of measurement terminology.[b] Black (chemical system)

Chart 13 continued on next page.

Chart 13 (Cont'd)



Given an unordered set of chemical word equations describing various interactions of Black's limestone cycle, the student identifies an equation that describes the preparation of quicklime or the formations of limestone. Black

Given a list of common names of three or more chemical substances with their corresponding chemical names and molecular formulas and given a description of an interaction involving these chemical substances, the student writes a chemical equation for the interaction using the chemical names or molecular formulas. Black

The student measures a subsystem (esophagus) of his body systems and responds to questions about comparative size and capacities of other subsystems (intestines, stomach) using appropriate scientific terminology for measurement.[a] Vesalius (systems)

The student describes his observations and measurements of length, mass, volume and temperature in appropriate metric measurement terminology and records his measurements using the appropriate notation. Lagrange (metric measurement)

Given lists of metric units, the student identifies units of length, mass, volume and temperature. Lagrange

Level C

The student measures linear dimensions and records them using the appropriate metric measurement terminology and notation.[a] Lagrange

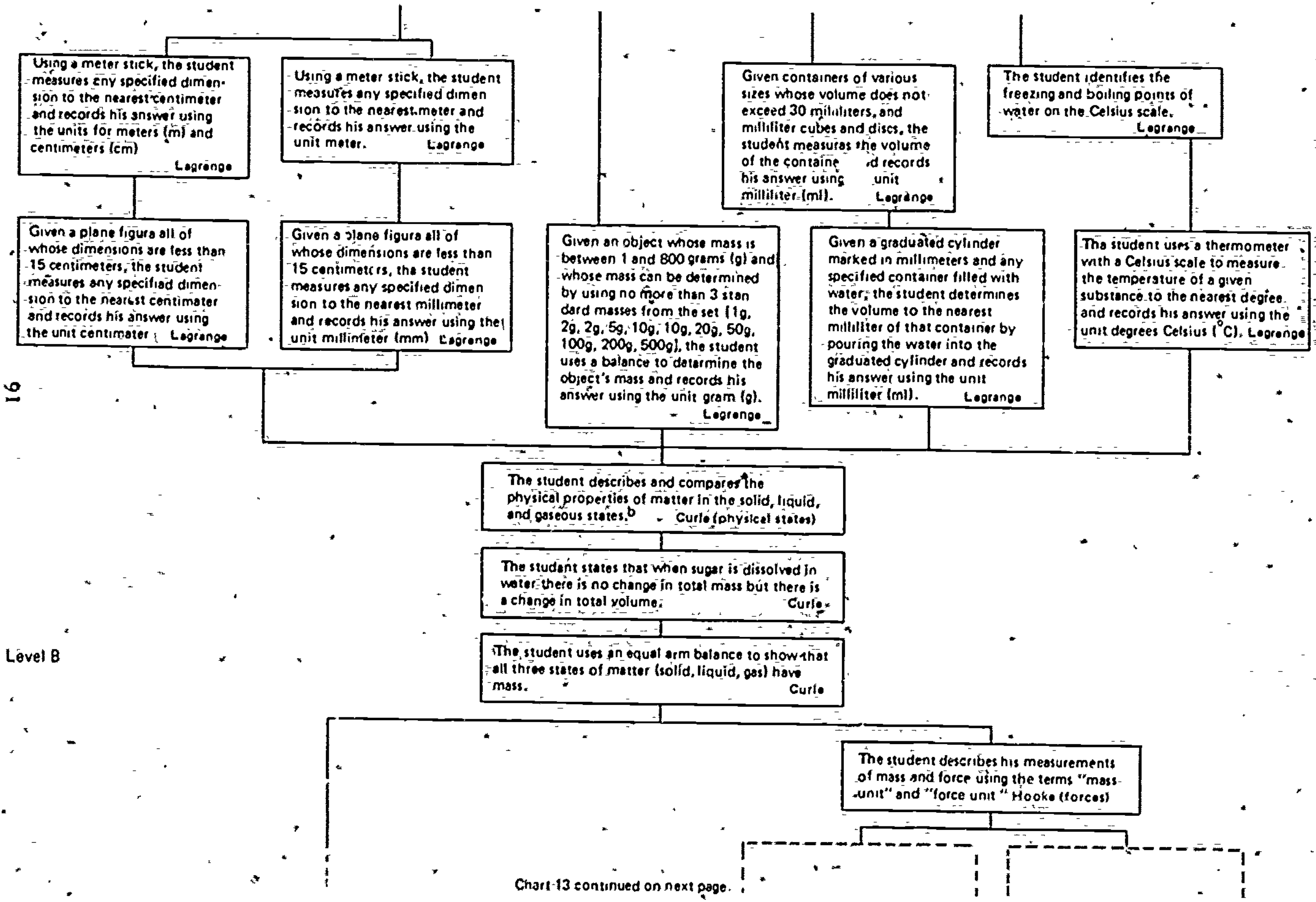
The student demonstrates that mass of an object and the gravitational force of attraction between the object and the earth are directly related and that different substance can occupy equal volumes.[a] Lagrange

The student measures and records temperature in degrees Celsius. Lagrange

The student identifies comparative relationships between different metric measures of volume.[a] Lagrange

Chart 13 continued on next page.

Chart 13 (Cont'd)



Using a meter stick, the student measures any specified dimension to the nearest centimeter and records his answer using the units for meters (m) and centimeters (cm) Lagrange

Using a meter stick, the student measures any specified dimension to the nearest meter and records his answer using the unit meter. Lagrange

Given containers of various sizes whose volume does not exceed 30 milliliters, and milliliter cubes and discs, the student measures the volume of the container and records his answer using the unit milliliter (ml). Lagrange

The student identifies the freezing and boiling points of water on the Celsius scale. Lagrange

Given a plane figure all of whose dimensions are less than 15 centimeters, the student measures any specified dimension to the nearest centimeter and records his answer using the unit centimeter Lagrange

Given a plane figure all of whose dimensions are less than 15 centimeters, the student measures any specified dimension to the nearest millimeter and records his answer using the unit millimeter (mm) Lagrange

Given an object whose mass is between 1 and 800 grams (g) and whose mass can be determined by using no more than 3 standard masses from the set {1g, 2g, 2g, 5g, 10g, 10g, 20g, 50g, 100g, 200g, 500g}, the student uses a balance to determine the object's mass and records his answer using the unit gram (g). Lagrange

Given a graduated cylinder marked in milliliters and any specified container filled with water, the student determines the volume to the nearest milliliter of that container by pouring the water into the graduated cylinder and records his answer using the unit milliliter (ml). Lagrange

The student uses a thermometer with a Celsius scale to measure the temperature of a given substance to the nearest degree and records his answer using the unit degrees Celsius (°C). Lagrange

The student describes and compares the physical properties of matter in the solid, liquid, and gaseous states.[b] Curie (physical states)

The student states that when sugar is dissolved in water there is no change in total mass but there is a change in total volume. Curie

The student uses an equal arm balance to show that all three states of matter (solid, liquid, gas) have mass. Curie

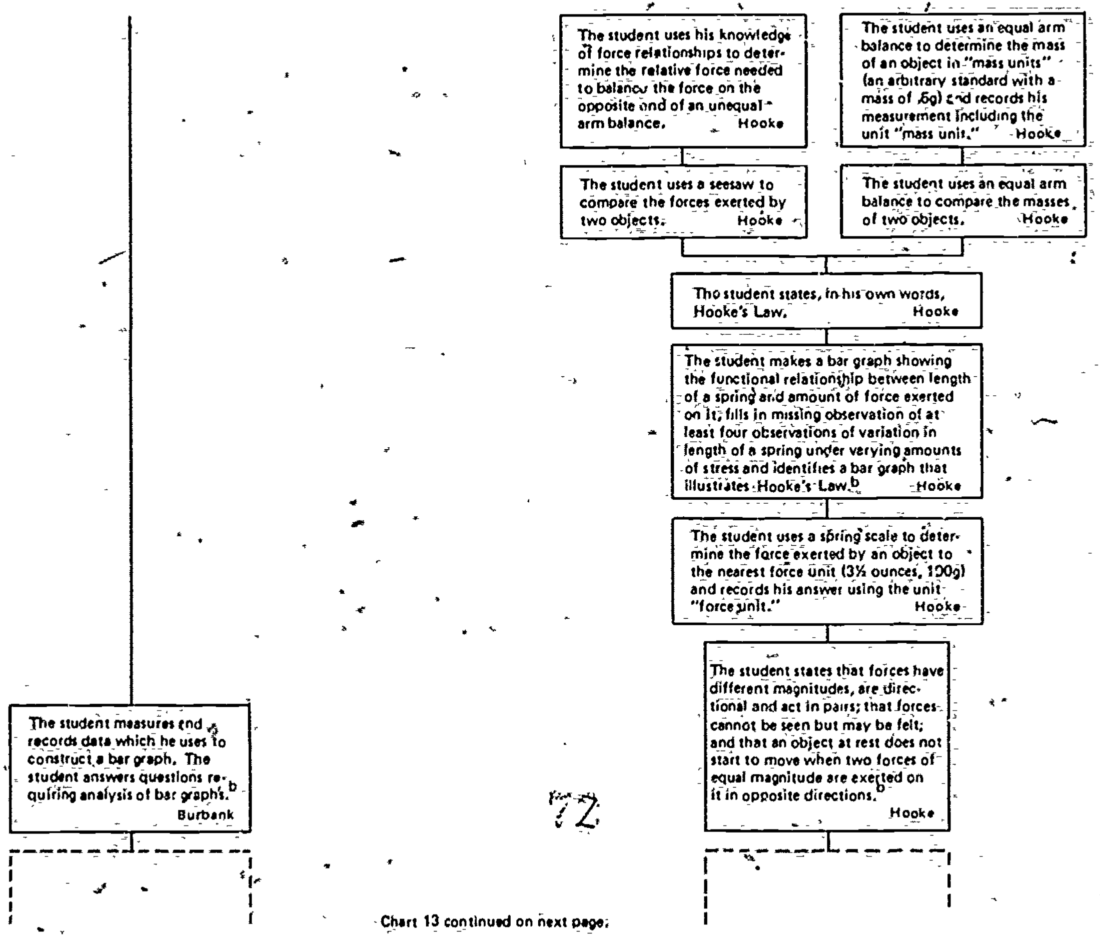
Level B

The student describes his measurements of mass and force using the terms "mass-unit" and "force unit" Hooke (forces)

Chart 13 continued on next page.

Chart 13 (Cont'd)

Level B



The student measures and records data which he uses to construct a bar graph. The student answers questions requiring analysis of bar graphs.[b] Burbank

The student uses his knowledge of force relationships to determine the relative force needed to balance the force on the opposite end of an unequal arm balance. Hooke

The student uses an equal arm balance to determine the mass of an object in "mass units" (an arbitrary standard with a mass of .5g) and records his measurement including the unit "mass unit." Hooke

The student uses a seesaw to compare the forces exerted by two objects. Hooke

The student uses an equal arm balance to compare the masses of two objects. Hooke

The student states, in his own words, Hooke's Law. Hooke

The student makes a bar graph showing the functional relationship between length of a spring and amount of force exerted on it; fills in missing observation of at least four observations of variation in length of a spring under varying amounts of stress and identifies a bar graph that illustrates Hooke's Law.[b] Hooke

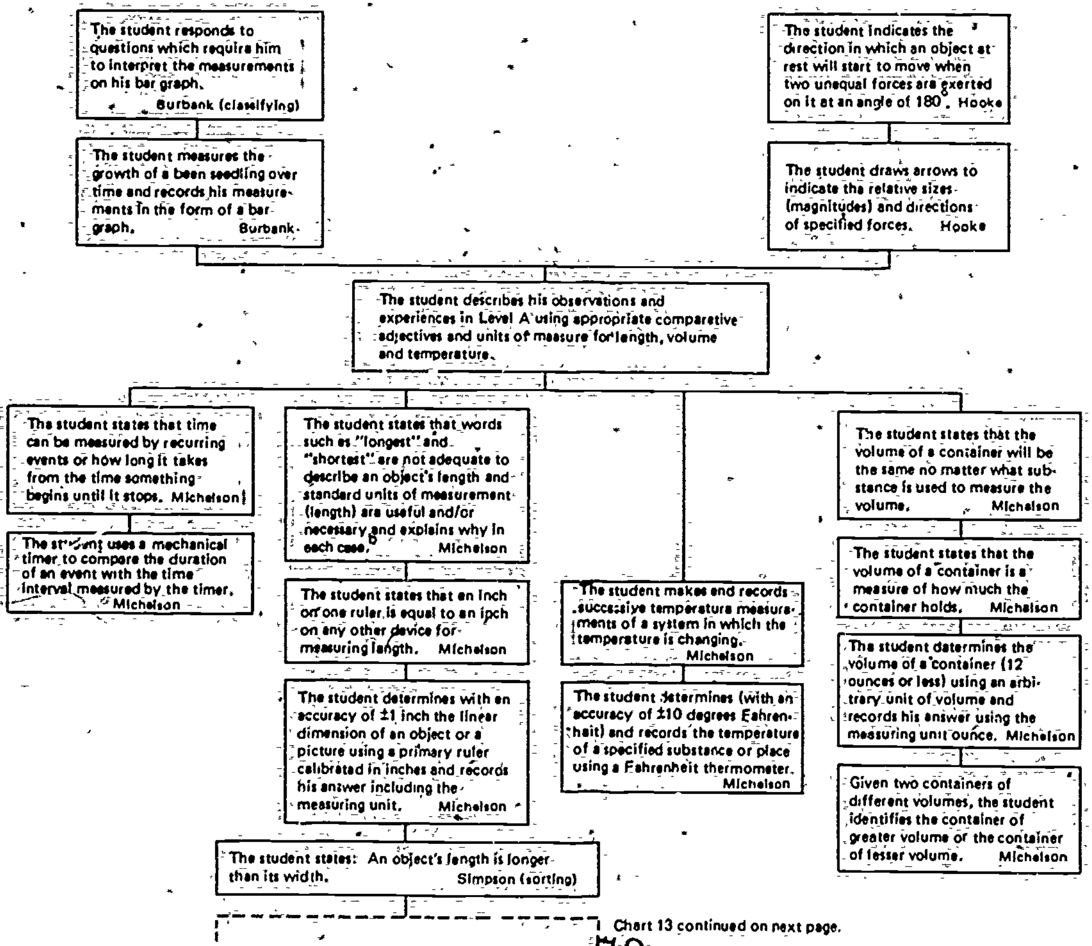
The student uses a spring scale to determine the force exerted by an object to the nearest force unit (3½ ounces, 100g) and records his answer using the unit "force unit." Hooke

The student states that forces have different magnitudes, are directional and act in pairs; that forces cannot be seen but may be felt; and that an object at rest does not start to move when two forces of equal magnitude are exerted on it in opposite directions.[b] Hooke

72

Chart 13 continued on next page.

Chart 13 (Cont'd)



The student responds to questions which require him to interpret the measurements on his bar graph. Burbank (classifying)

The student measures the growth of a bean seedling over time and records his measurements in the form of a bar graph. Burbank

The student indicates the direction in which an object at rest will start to move when two unequal forces are exerted on it at an angle of 180°. Hooke

The student draws arrows to indicate the relative sizes (magnitudes) and directions of specified forces. Hooke

The student describes his observations and experiences in Level A using appropriate comparative adjectives and units of measure for length, volume and temperature.

Level A

The student states that time can be measured by recurring events or how long it takes from the time something begins until it stops. Michelson

The student uses a mechanical timer to compare the duration of an event with the time interval measured by the timer. Michelson

The student states that words such as "longest" and "shortest" are not adequate to describe an object's length and standard units of measurement (length) are useful and/or necessary and explains why in each case. Michelson

The student states that an inch on one ruler is equal to an inch on any other device for measuring length. Michelson

The student determines with an accuracy of ±1 inch the linear dimension of an object or a picture using a primary ruler calibrated in inches and records his answer including the measuring unit. Michelson

The student states: An object's length is longer than its width. Simpson (sorting)

The student makes and records successive temperature measurements of a system in which the temperature is changing. Michelson

The student determines (with an accuracy of ±10 degrees Fahrenheit) and records the temperature of a specified substance or place using a Fahrenheit thermometer. Michelson

The student states that the volume of a container will be the same no matter what substance is used to measure the volume. Michelson

The student states that the volume of a container is a measure of how much the container holds. Michelson

The student determines the volume of a container (12 ounces or less) using an arbitrary unit of volume and records his answer using the measuring unit ounce. Michelson

Given two containers of different volumes, the student identifies the container of greater volume or the container of lesser volume. Michelson

Chart 13 continued on next page.

Chart 13 (Cont'd)

Level A

Given four objects of the same shape, differing in width and length, the student describes the widest and narrowest using the terms "widest" and "narrowest", describes the longest and shortest using the terms "longest" and "shortest" and orders the objects by length and width.[b] Simpson

Given four objects of the same shape differing in height and width, the student describes the tallest and shortest objects using the terms "tallest" and "shortest" and orders by height.[b] Simpson

Given three different sized objects of the same shape and of either the same color or different colors, the student describes the objects using the terms "largest," "smallest" and "medium-sized" and orders by size.[b] Simpson

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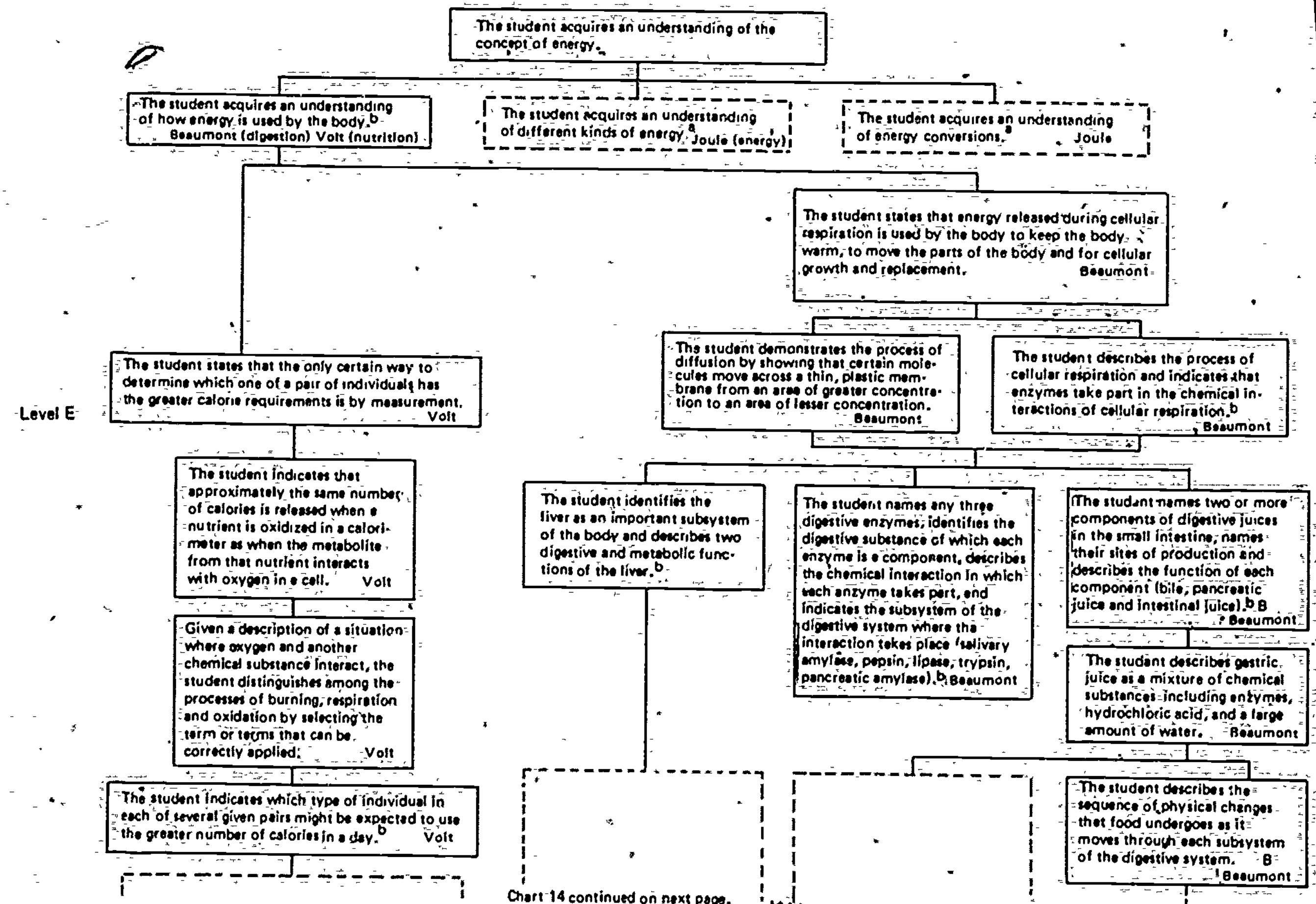
Prerequisites:

Sorting on shape, color and identifying color and shape as basis of sort.[b] Simpson

[a] objective added to developers' objectives

[b] developers' objective reworded or two or more combined

Curriculum Analysis of Individualized Science: Illustrative Hierarchy of Science Concepts Subgoal I-2–
Concept of Energy



The student acquires an understanding of the concept of energy.

The student acquires an understanding of how energy is used by the body.[b] Beaumont (digestion) Volt (nutrition)

The student acquires an understanding of different kinds of energy.[a] Joule (energy)

The student acquires an understanding of energy conversions.[a] Joule

The student states that energy released during cellular respiration is used by the body to keep the body warm, to move the parts of the body and for cellular growth and replacement. Beaumont

The student states that the only certain way to determine which one of a pair of individuals has the greater calorie requirements is by measurement. Volt

The student demonstrates the process of diffusion by showing that certain molecules move across a thin, plastic membrane from an area of greater concentration to an area of lesser concentration. Beaumont

The student describes the process of cellular respiration and indicates that enzymes take part in the chemical interactions of cellular respiration.[b] Beaumont

The student indicates that approximately the same number of calories is released when a nutrient is oxidized in a calorimeter as when the metabolite from that nutrient interacts with oxygen in a cell. Volt

The student identifies the liver as an important subsystem of the body and describes two digestive and metabolic functions of the liver.[b]

The student names any three digestive enzymes, identifies the digestive substance of which each enzyme is a component, describes the chemical interaction in which each enzyme takes part, and indicates the subsystem of the digestive system where the interaction takes place (salivary amylase, pepsin, lipase, trypsin, pancreatic amylase).[b] Beaumont

The student names two or more components of digestive juices in the small intestine, names their sites of production and describes the function of each component (bile, pancreatic juice and intestinal juice).[b] B Beaumont

Given a description of a situation where oxygen and another chemical substance interact, the student distinguishes among the processes of burning, respiration and oxidation by selecting the term or terms that can be correctly applied. Volt

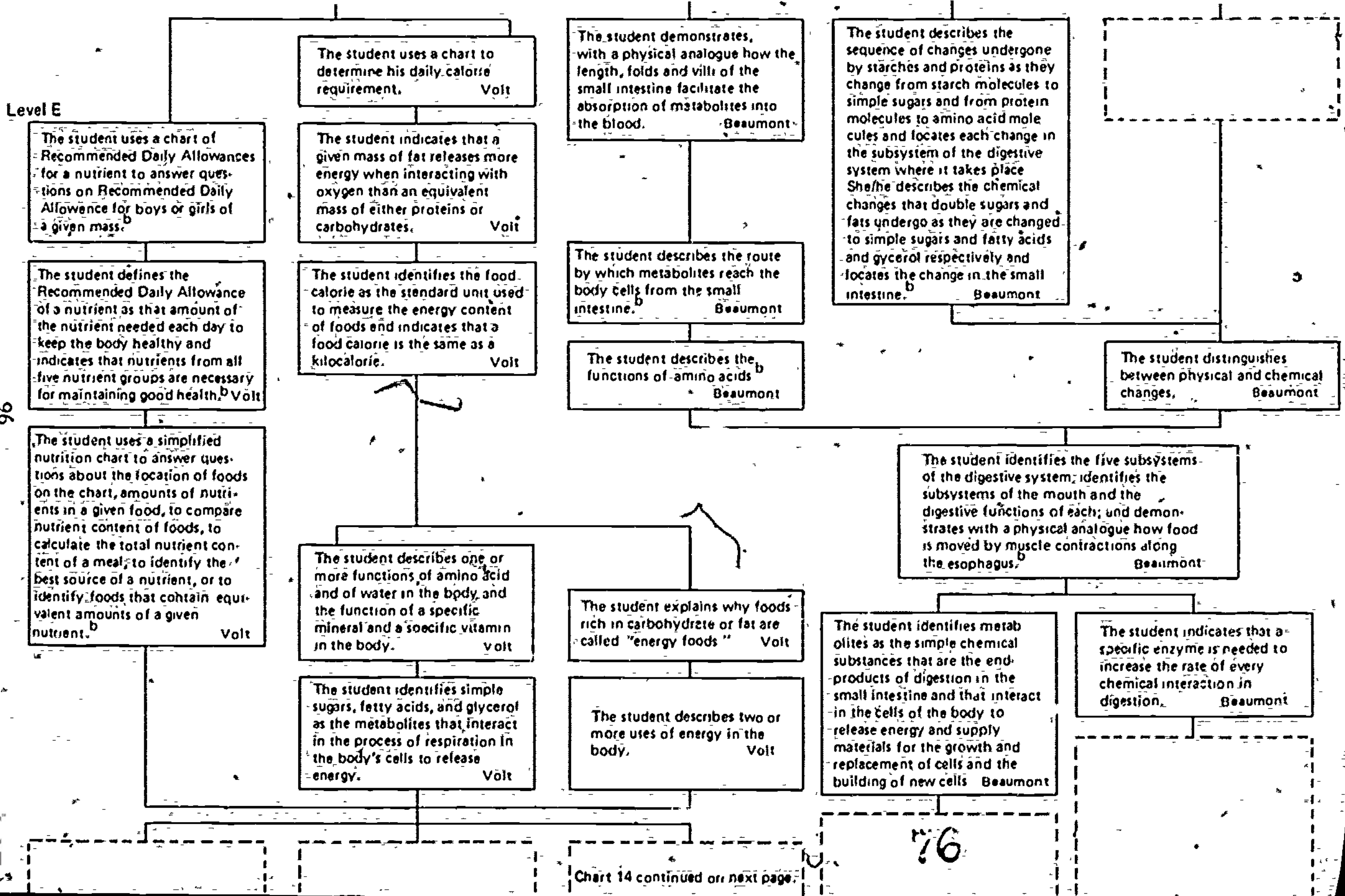
The student describes gastric juice as a mixture of chemical substances including enzymes, hydrochloric acid, and a large amount of water. Beaumont

The student indicates which type of individual in each of several given pairs might be expected to use the greater number of calories in a day.[b] Volt

The student describes the sequence of physical changes that food undergoes as it moves through each subsystem of the digestive system. B Beaumont

Chart 14 continued on next page.

Chart 14 (Cont'd)



Level E

The student uses a chart of Recommended Daily Allowances for a nutrient to answer questions on Recommended Daily Allowance for boys or girls of a given mass.[b]

The student defines the Recommended Daily Allowance of a nutrient as that amount of the nutrient needed each day to keep the body healthy and indicates that nutrients from all five nutrient groups are necessary for maintaining good health.[b] Volt

The student uses a simplified nutrition chart to answer questions about the location of foods on the chart, amounts of nutrients in a given food, to compare nutrient content of foods, to calculate the total nutrient content of a meal, to identify the best source of a nutrient, or to identify foods that contain equivalent amounts of a given nutrient.[b] Volt

The student uses a chart to determine his daily calorie requirement. Volt

The student indicates that a given mass of fat releases more energy when interacting with oxygen than an equivalent mass of either proteins or carbohydrates. Volt

The student identifies the food calorie as the standard unit used to measure the energy content of foods and indicates that a food calorie is the same as a kilocalorie. Volt

The student describes one or more functions of amino acid and of water in the body and the function of a specific mineral and a specific vitamin in the body. Volt

The student identifies simple sugars, fatty acids, and glycerol as the metabolites that interact in the process of respiration in the body's cells to release energy. Volt

The student demonstrates, with a physical analogue how the length, folds and villi of the small intestine facilitate the absorption of metabolites into the blood. Beaumont

The student describes the route by which metabolites reach the body cells from the small intestine.[b] Beaumont

The student describes the functions of amino acids[b] Beaumont

The student explains why foods rich in carbohydrate or fat are called "energy foods." Volt

The student describes two or more uses of energy in the body. Volt

The student describes the sequence of changes undergone by starches and proteins as they change from starch molecules to simple sugars and from protein molecules to amino acid molecules and locates each change in the subsystem of the digestive system where it takes place. She/he describes the chemical changes that double sugars and fats undergo as they are changed to simple sugars and fatty acids and gycerol respectively and locates the change in the small intestine.[b] Beaumont

The student distinguishes between physical and chemical changes. Beaumont

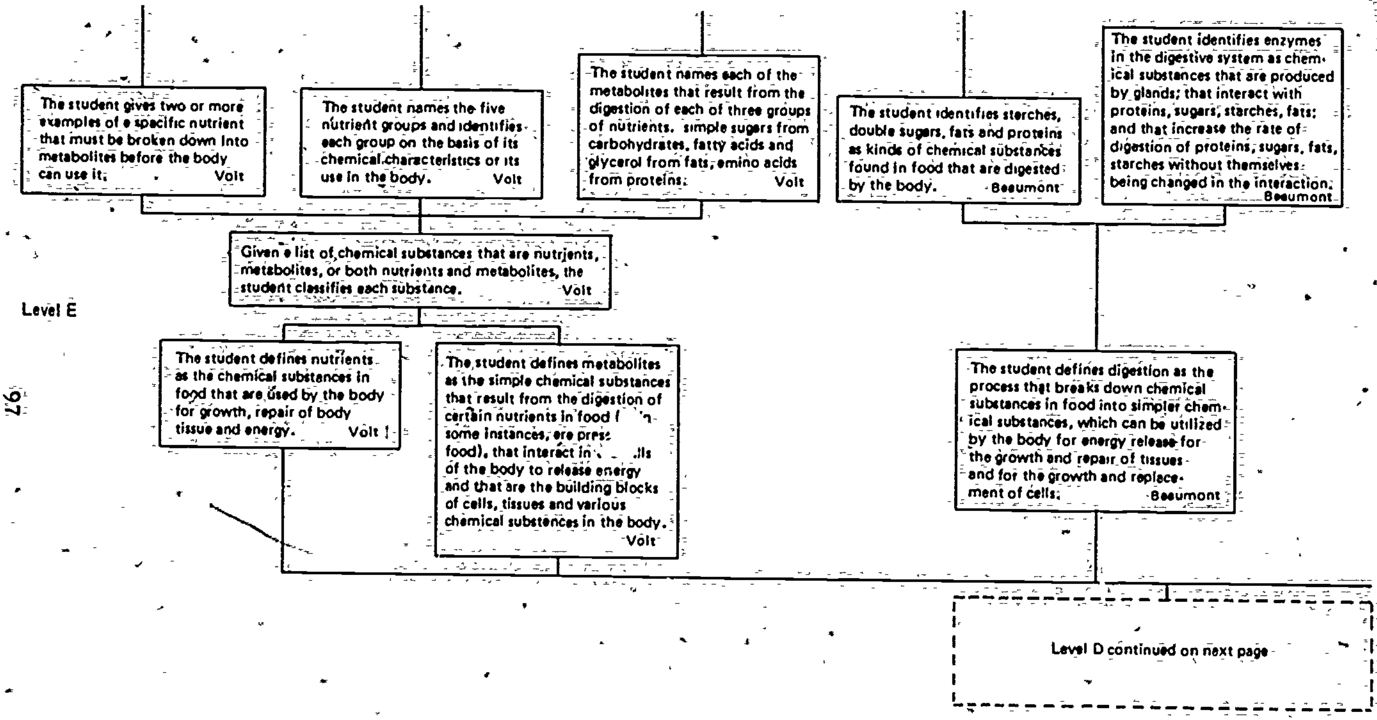
The student identifies the five subsystems of the digestive system; identifies the subsystems of the mouth and the digestive functions of each; and demonstrates with a physical analogue how food is moved by muscle contractions along the esophagus.[b] Beaumont

The student identifies metabolites as the simple chemical substances that are the end-products of digestion in the small intestine and that interact in the cells of the body to release energy and supply materials for the growth and replacement of cells and the building of new cells. Beaumont

The student indicates that a specific enzyme is needed to increase the rate of every chemical interaction in digestion. Beaumont

Chart 14 continued on next page.

Chart 14 (Cont'd)



The student gives two or more examples of a specific nutrient that must be broken down into metabolites before the body can use it. Volt

The student names the five nutrient groups and identifies each group on the basis of its chemical characteristics or its use in the body. Volt

The student names each of the metabolites that result from the digestion of each of three groups of nutrients. simple sugars from carbohydrates, fatty acids and glycerol from fats, amino acids from proteins. Volt

The student identifies starches, double sugars, fats and proteins as kinds of chemical substances found in food that are digested by the body. Beaumont

The student identifies enzymes in the digestive system as chemical substances that are produced by glands; that interact with proteins, sugars, starches, fats; and that increase the rate of digestion of proteins, sugars, fats, starches without themselves being changed in the interaction. Beaumont

Given a list of chemical substances that are nutrients, metabolites, or both nutrients and metabolites, the student classifies each substance. Volt

Level E

The student defines nutrients as the chemical substances in food that are used by the body for growth, repair of body tissue and energy. Volt

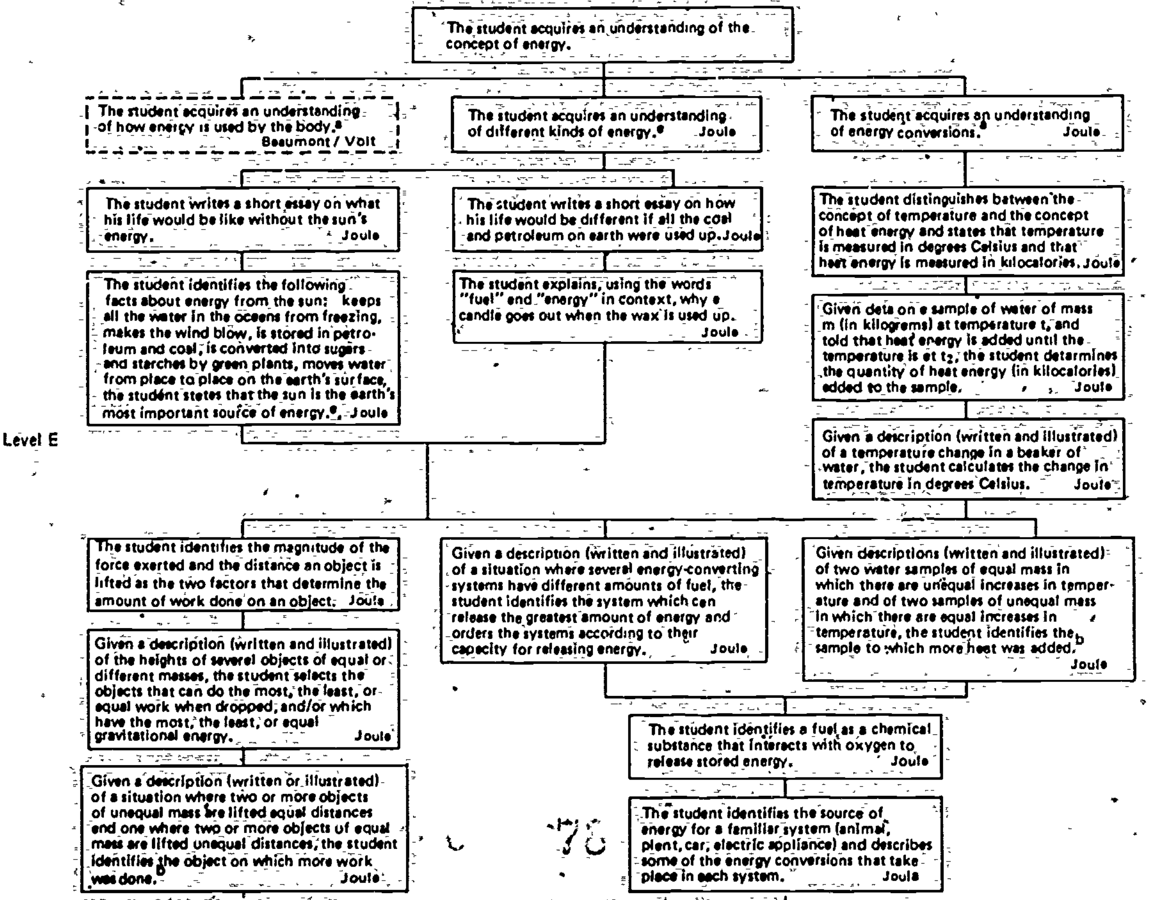
The student defines metabolites as the simple chemical substances that result from the digestion of certain nutrients in food (in some instances, are pres[illegible] food), that interact in [illegible] cells of the body to release energy and that are the building blocks of cells, tissues and various chemical substances in the body. Volt

The student defines digestion as the process that breaks down chemical substances in food into simpler chemical substances, which can be utilized by the body for energy release for the growth and repair of tissues and for the growth and replacement of cells. Beaumont

Level D continued on next page

(Chart 14 Level E continued on next page.)

Chart 14 (Cont'd)



The student acquires an understanding of the concept of energy.

The student acquires an understanding of how energy is used by the body.[a] Beaumont / Volt

The student acquires an understanding of different kinds of energy.[a] Joule

The student acquires an understanding of energy conversions.[a] Joule

The student writes a short essay on what his life would be like without the sun's energy. Joule

The student identifies the following facts about energy from the sun: keeps all the water in the oceans from freezing, makes the wind blow, is stored in petroleum and coal, is converted into sugars and starches by green plants, moves water from place to place on the earth's surface, the student states that the sun is the earth's most important source of energy.[a] Joule

The student writes a short essay on how his life would be different if all the coal and petroleum on earth were used up. Joule

The student explains, using the words "fuel" and "energy" in context, why a candle goes out when the wax is used up. Joule

The student distinguishes between the concept of temperature and the concept of heat energy and states that temperature is measured in degrees Celsius and that heat energy is measured in kilocalories. Joule

Given data on a sample of water of mass m (in kilograms) at temperature t_1 and told that heat energy is added until the temperature is at t_2, the student determines the quantity of heat energy (in kilocalories) added to the sample. Joule

Given a description (written and illustrated) of a temperature change in a beaker of water, the student calculates the change in temperature in degrees Celsius. Joule

The student identifies the magnitude of the force exerted and the distance an object is lifted as the two factors that determine the amount of work done on an object. Joule

Given a description (written and illustrated) of the heights of several objects of equal or different masses, the student selects the objects that can do the most, the least, or equal work when dropped, and/or which have the most, the least, or equal gravitational energy. Joule

Given a description (written or illustrated) of a situation where two or more objects of unequal mass are lifted equal distances and one where two or more objects of equal mass are lifted unequal distances, the student identifies the object on which more work was done.[b] Joule

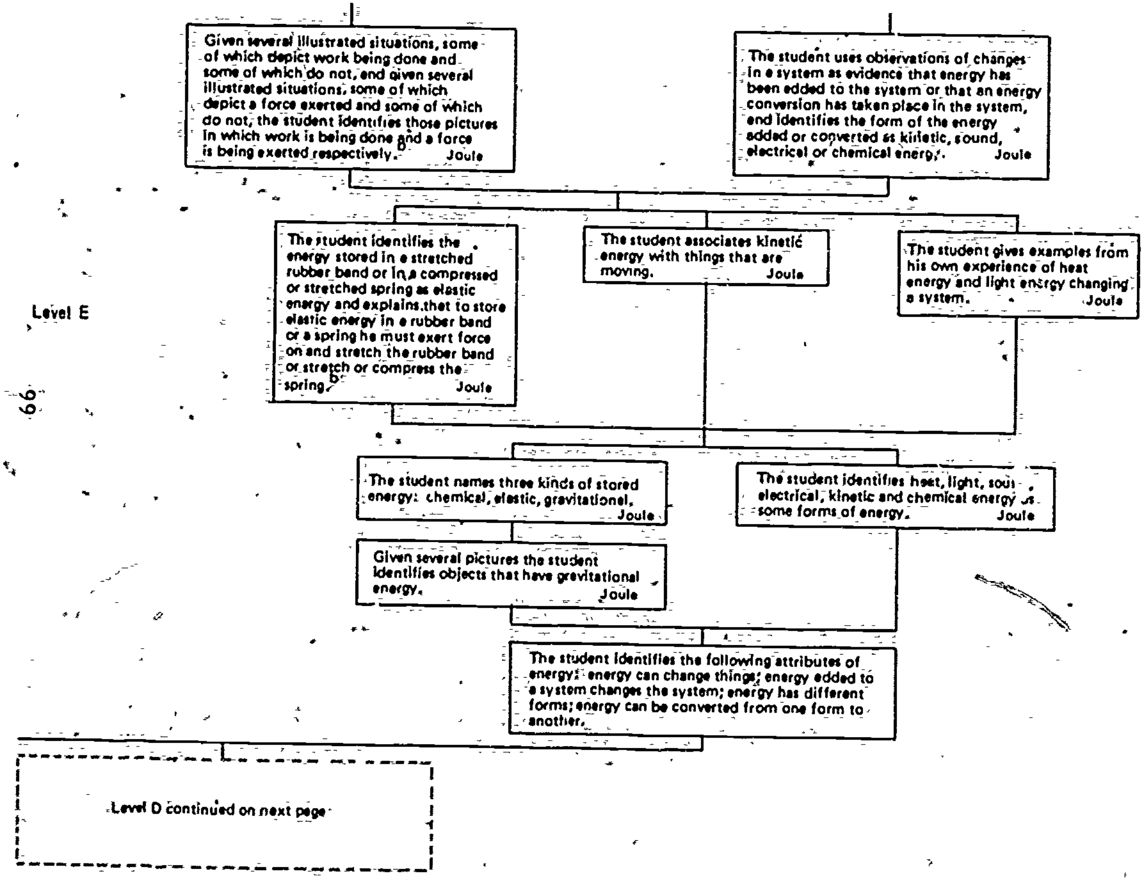
Given a description (written and illustrated) of a situation where several energy-converting systems have different amounts of fuel, the student identifies the system which can release the greatest amount of energy and orders the systems according to their capacity for releasing energy. Joule

Given descriptions (written and illustrated) of two water samples of equal mass in which there are unequal increases in temperature and of two samples of unequal mass in which there are equal increases in temperature, the student identifies the sample to which more heat was added.[b] Joule

The student identifies a fuel as a chemical substance that interacts with oxygen to release stored energy. Joule

The student identifies the source of energy for a familiar system (animal, plant, car, electric appliance) and describes some of the energy conversions that take place in each system. Joule

Chart 14 continued on next page.



Given several illustrated situations, some of which depict work being done and some of which do not, and given several illustrated situations, some of which depict a force exerted and some of which do not, the student identifies those pictures in which work is being done and a force is being exerted respectively. Joule

The student uses observations of changes in a system as evidence that energy has been added to the system or that an energy conversion has taken place in the system, and identifies the form of the energy added or converted as kinetic, sound, electrical or chemical energy. Joule

Level E

The student identifies the energy stored in a stretched rubber band or in a compressed or stretched spring as elastic energy and explains that to store elastic energy in a rubber band or a spring he must exert force on and stretch the rubber band or stretch or compress the spring. Joule

The student associates kinetic energy with things that are moving. Joule

The student gives examples from his own experience of heat energy and light energy changing a system. Joule

The student names three kinds of stored energy: chemical, elastic, gravitational. Joule

The student identifies heat, light, sound, electrical, kinetic and chemical energy as some forms of energy. Joule

Given several pictures the student identifies objects that have gravitational energy. Joule

The student identifies the following attributes of energy: energy can change things; energy added to a system changes the system; energy has different forms; energy can be converted from one form to another.

Level D continued on next page

Chart 14 continued on next page.

Chart 14 (Cont'd)

Level D

In Level D the student is introduced to the concept of energy by observing the interaction of oxygen with chemical substances under differing conditions, an interaction which produces carbon dioxide and water vapor and releases energy.[a] Lavoisier (burning) Haldane (breathing) Dalton (atoms and molecules)

The student indicates three ways in which the processes of burning and respiration are similar and at least one way in which they are different. Haldane

When asked to give an explanation of the process of respiration (or to select the best explanation from among three or more suggested explanations), the student states (or selects the one suggested explanation which states) that during the process of respiration oxygen interacts with chemical substances from the food an animal eats and that energy (heat and motion) is released and carbon dioxide and water are produced. Haldane

The student writes an equation describing the process of respiration. Haldane

The student applies in a novel situation the concept that animals consume oxygen and produce carbon dioxide and water vapor. Haldane

The student applies in a novel situation the concept that oxygen is necessary to maintain animal life. Haldane

The student demonstrates his comprehension of the chemical symbols N_2 for nitrogen gas, O_2 for oxygen gas, and CO_2 for carbon dioxide gas by translating expressions in words to the corresponding expressions in chemical symbols. Haldane

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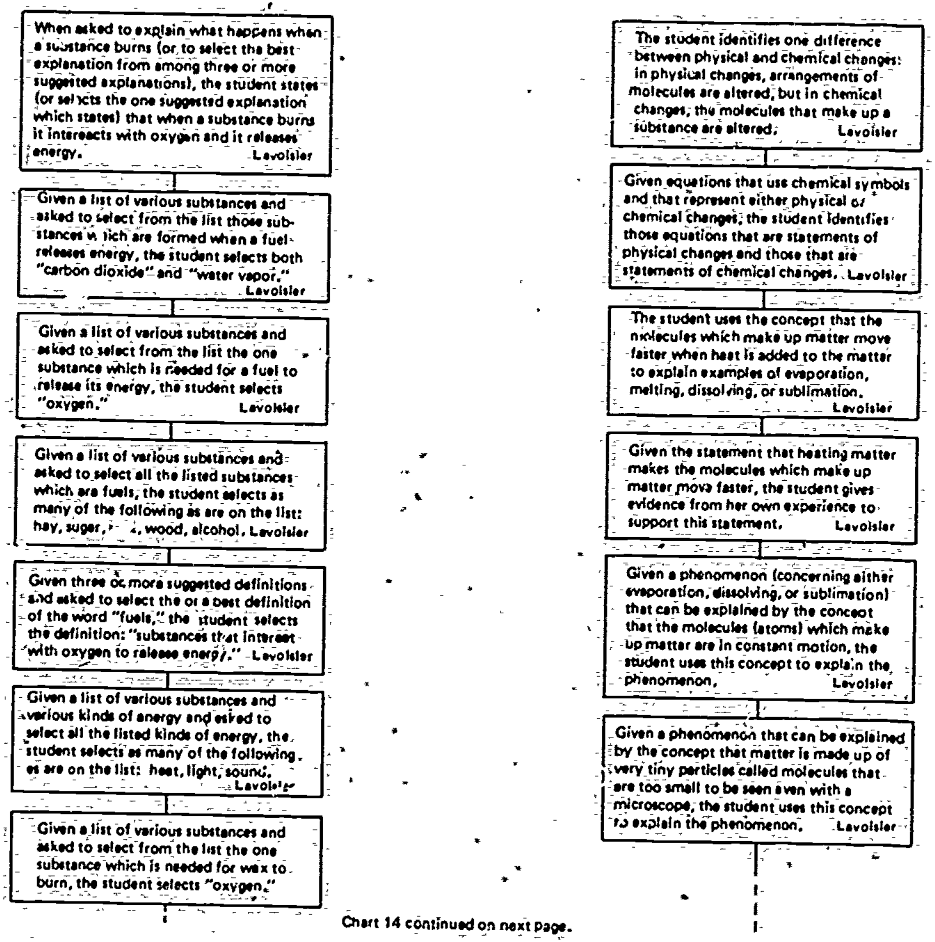
Chart 14 (Cont'd)



When asked to explain what happens when a substance burns (or to select the best explanation from among three or more suggested explanations), the student states (or selects the one suggested explanation which states) that when a substance burns it interacts with oxygen and it releases energy. Lavoisier

Given a list of various substances and asked to select from the list those substances which are formed when a fuel releases energy, the student selects both "carbon dioxide" and "water vapor." Lavoisier

Given a list of various substances and asked to select from the list the one substance which is needed for a fuel to release its energy, the student selects "oxygen." Lavoisier

Given a list of various substances and asked to select all the listed substances which are fuels, the student selects as many of the following as are on the list: hay, sugar, [illegible], wood, alcohol. Lavoisier

Given three or more suggested definitions and asked to select the or a best definition of the word "fuels," the student selects the definition: "substances that interact with oxygen to release energy." Lavoisier

Given a list of various substances and various kinds of energy and asked to select all the listed kinds of energy, the student selects as many of the following as are on the list: heat, light, sound. Lavoisier

Given a list of various substances and asked to select from the list the one substance which is needed for wax to burn, the student selects "oxygen."

The student identifies one difference between physical and chemical changes: in physical changes, arrangements of molecules are altered, but in chemical changes, the molecules that make up a substance are altered. Lavoisier

Given equations that use chemical symbols and that represent either physical or chemical changes, the student identifies those equations that are statements of physical changes and those that are statements of chemical changes. Lavoisier

The student uses the concept that the molecules which make up matter move faster when heat is added to the matter to explain examples of evaporation, melting, dissolving, or sublimation. Lavoisier

Given the statement that heating matter makes the molecules which make up matter move faster, the student gives evidence from her own experience to support this statement. Lavoisier

Given a phenomenon (concerning either evaporation, dissolving, or sublimation) that can be explained by the concept that the molecules (atoms) which make up matter are in constant motion, the student uses this concept to explain the phenomenon. Lavoisier

Given a phenomenon that can be explained by the concept that matter is made up of very tiny particles called molecules that are too small to be seen even with a microscope, the student uses this concept to explain the phenomenon. Lavoisier

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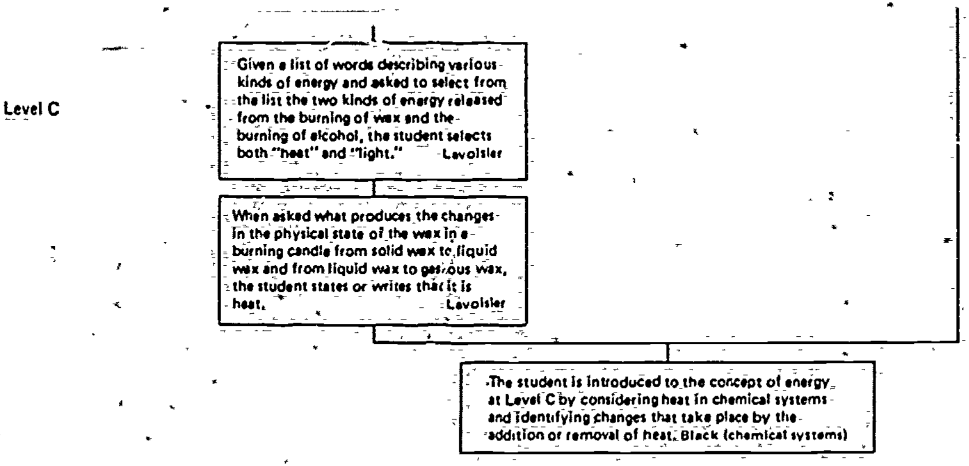
Chart 14 (Cont'd)



Given a list of words describing various kinds of energy and asked to select from the list the two kinds of energy released from the burning of wax and the burning of alcohol, the student selects both "heat" and "light." Lavoisier

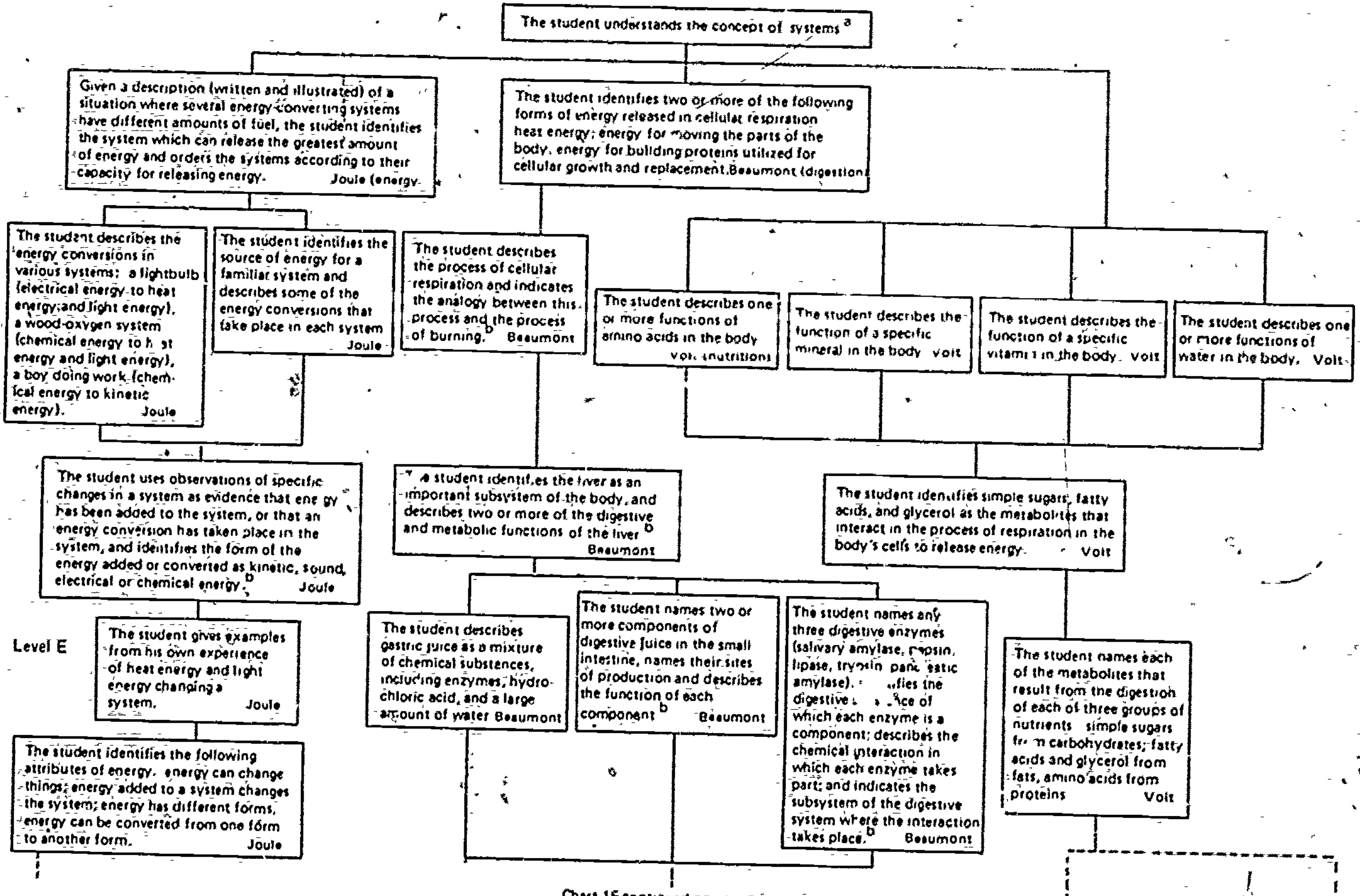
When asked what produces the changes in the physical state of the wax in a burning candle from solid wax to liquid wax and from liquid wax to gaseous wax, the student states or writes that it is heat. Lavoisier

The student is introduced to the concept of energy at Level C by considering heat in chemical systems and identifying changes that take place by the addition or removal of heat. Black (chemical systems)

[a] objective added to developers' objective

[b] objective abbreviated or two or more objectives combined

Curriculum Analysis of Individualized Science: Illustrative Hierarchy of Science Concepts Subgoal 1-2 — System Concepts



The student understands the concept of systems[a]

Given a description (written and illustrated) of a situation where several energy-converting systems have different amounts of fuel, the student identifies the system which can release the greatest amount of energy and orders the systems according to their capacity for releasing energy. Joule (energy

The student identifies two or more of the following forms of energy released in cellular respiration heat energy; energy for moving the parts of the body, energy for building proteins utilized for cellular growth and replacement. Beaumont (digestion)

The student describes the energy conversions in various systems: a lightbulb (electrical energy to heat energy and light energy), a wood-oxygen system (chemical energy to heat energy and light energy), a boy doing work (chemical energy to kinetic energy). Joule

The student identifies the source of energy for a familiar system and describes some of the energy conversions that take place in each system Joule

The student describes the process of cellular respiration and indicates the analogy between this process and the process of burning.[b] Beaumont

The student describes one or more functions of amino acids in the body Volt (nutrition)

The student describes the function of a specific mineral in the body Volt

The student describes the function of a specific vitamin in the body. Volt

The student describes one or more functions of water in the body. Volt

The student uses observations of specific changes in a system as evidence that energy has been added to the system, or that an energy conversion has taken place in the system, and identifies the form of the energy added or converted as kinetic, sound, electrical or chemical energy.[b] Joule

The student identifies the liver as an important subsystem of the body, and describes two or more of the digestive and metabolic functions of the liver[b] Beaumont

The student identifies simple sugars, fatty acids, and glycerol as the metabolites that interact in the process of respiration in the body's cells to release energy. Volt

Level E

The student gives examples from his own experience of heat energy and light energy changing a system. Joule

The student describes gastric juice as a mixture of chemical substances, including enzymes, hydrochloric acid, and a large amount of water Beaumont

The student names two or more components of digestive juice in the small intestine, names their sites of production and describes the function of each component[b] Beaumont

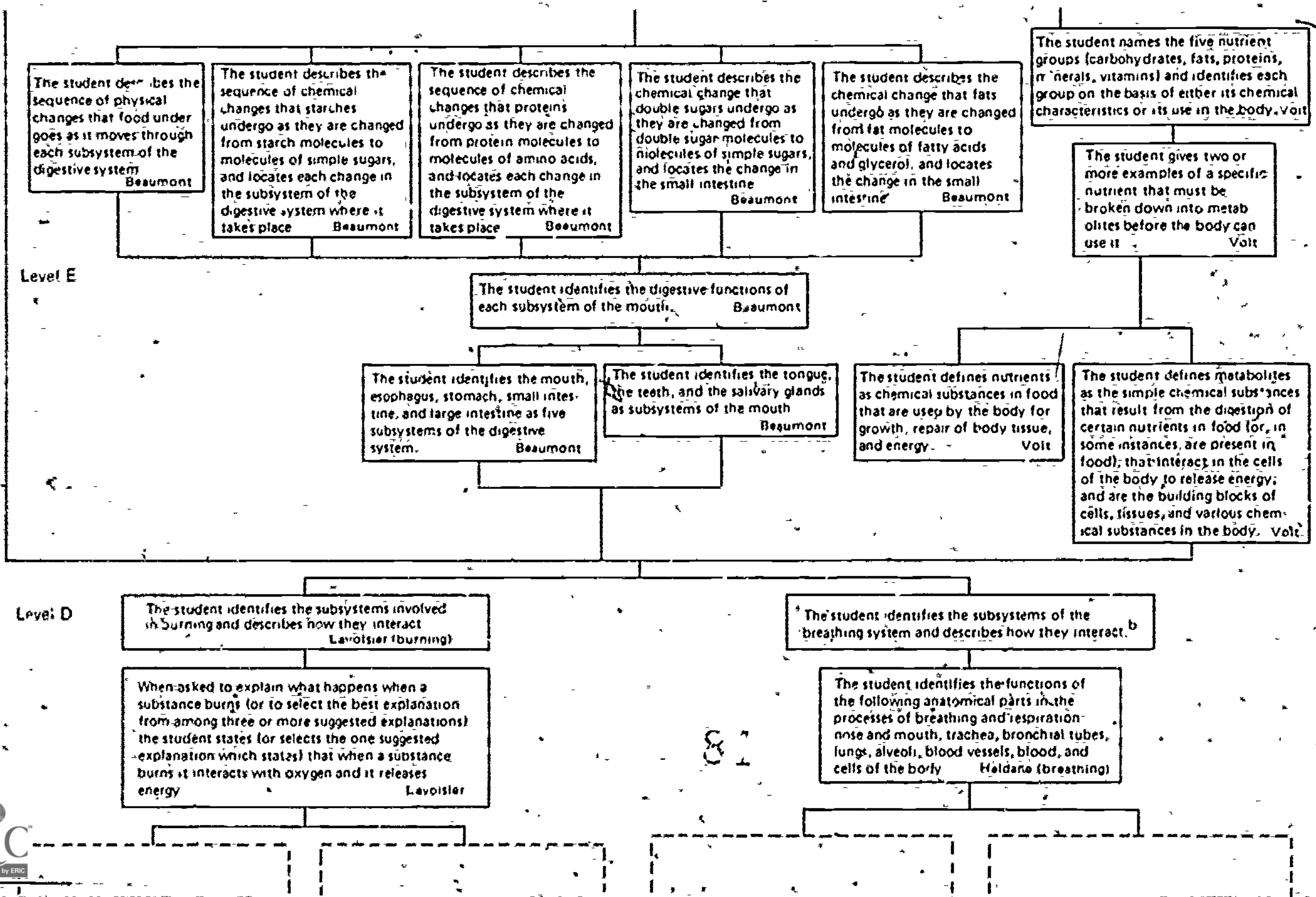
The student names any three digestive enzymes (salivary amylase, pepsin, lipase, trypsin pancreatic amylase); identifies the digestive juice of which each enzyme is a component; describes the chemical interaction in which each enzyme takes part; and indicates the subsystem of the digestive system where the interaction takes place.[b] Beaumont

The student names each of the metabolites that result from the digestion of each of three groups of nutrients simple sugars from carbohydrates; fatty acids and glycerol from fats, amino acids from proteins Volt

The student identifies the following attributes of energy. energy can change things; energy added to a system changes the system; energy has different forms, energy can be converted from one form to another form. Joule

Chart 15 continued on next page.

Chart 15 (Cont'd)



Level E

The student describes the sequence of physical changes that food undergoes as it moves through each subsystem of the digestive system Beaumont

The student describes the sequence of chemical changes that starches undergo as they are changed from starch molecules to molecules of simple sugars, and locates each change in the subsystem of the digestive system where it takes place Beaumont

The student describes the sequence of chemical changes that proteins undergo as they are changed from protein molecules to molecules of amino acids, and locates each change in the subsystem of the digestive system where it takes place Beaumont

The student describes the chemical change that double sugars undergo as they are changed from double sugar molecules to molecules of simple sugars, and locates the change in the small intestine Beaumont

The student describes the chemical change that fats undergo as they are changed from fat molecules to molecules of fatty acids and glycerol, and locates the change in the small intestine Beaumont

The student names the five nutrient groups (carbohydrates, fats, proteins, minerals, vitamins) and identifies each group on the basis of either its chemical characteristics or its use in the body. Voit

The student gives two or more examples of a specific nutrient that must be broken down into metabolites before the body can use it Voit

The student identifies the digestive functions of each subsystem of the mouth. Beaumont

The student identifies the mouth, esophagus, stomach, small intestine, and large intestine as five subsystems of the digestive system. Beaumont

The student identifies the tongue, the teeth, and the salivary glands as subsystems of the mouth Beaumont

The student defines nutrients as chemical substances in food that are used by the body for growth, repair of body tissue, and energy. Voit

The student defines metabolites as the simple chemical substances that result from the digestion of certain nutrients in food (or, in some instances, are present in food); that interact in the cells of the body to release energy; and are the building blocks of cells, tissues, and various chemical substances in the body. Voit

Level D

The student identifies the subsystems involved in burning and describes how they interact Lavoisier (burning)

When asked to explain what happens when a substance burns (or to select the best explanation from among three or more suggested explanations) the student states (or selects the one suggested explanation which states) that when a substance burns it interacts with oxygen and it releases energy Lavoisier

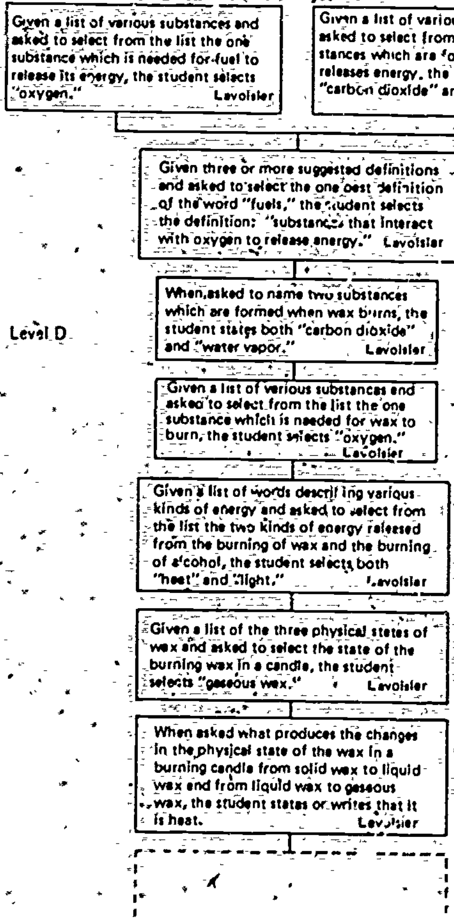
The student identifies the subsystems of the breathing system and describes how they interact.[b]

The student identifies the functions of the following anatomical parts in the processes of breathing and respiration: nose and mouth, trachea, bronchial tubes, lungs, alveoli, blood vessels, blood, and cells of the body Haldane (breathing)

Chart 15 continued on next page

Chart 15 (Cont'd)

Level D



Given a list of various substances and asked to select from the list the one substance which is needed for fuel to release its energy, the student selects "oxygen." Lavoisier

Given a list of various substances and asked to select from the list those substances which are formed when a fuel releases energy, the student selects both "carbon dioxide" and "water vapor." Lavoisier

Given three or more suggested definitions and asked to select the one best definition of the word "fuels," the student selects the definition: "substances that interact with oxygen to release energy." Lavoisier

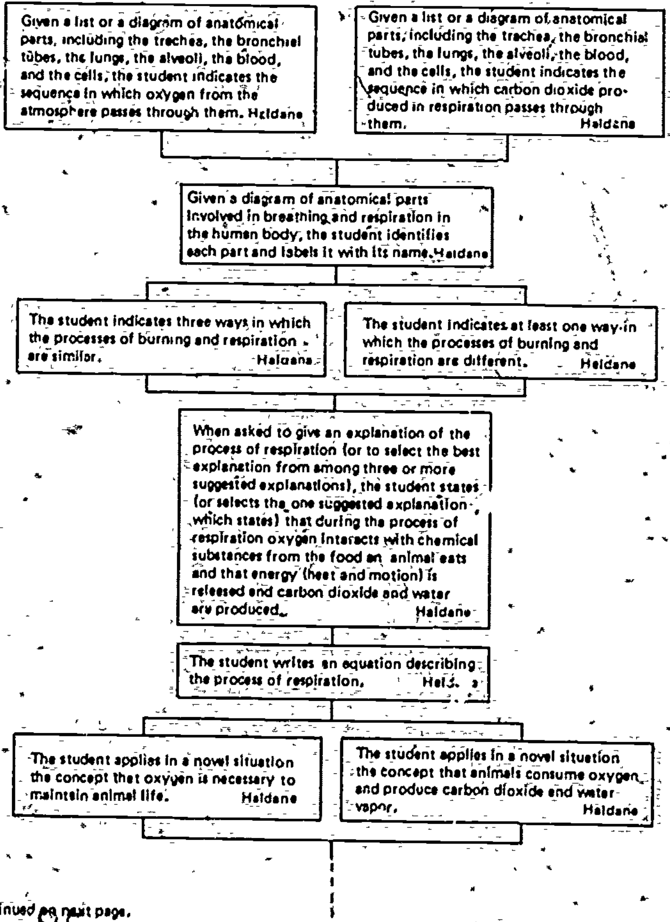
When asked to name two substances which are formed when wax burns, the student states both "carbon dioxide" and "water vapor." Lavoisier

Given a list of various substances and asked to select from the list the one substance which is needed for wax to burn, the student selects "oxygen." Lavoisier

Given a list of words describing various kinds of energy and asked to select from the list the two kinds of energy released from the burning of wax and the burning of alcohol, the student selects both "heat" and "light." Lavoisier

Given a list of the three physical states of wax and asked to select the state of the burning wax in a candle, the student selects "gaseous wax." Lavoisier

When asked what produces the changes in the physical state of the wax in a burning candle from solid wax to liquid wax and from liquid wax to gaseous wax, the student states or writes that it is heat. Lavoisier



Given a list or a diagram of anatomical parts, including the trachea, the bronchial tubes, the lungs, the alveoli, the blood, and the cells, the student indicates the sequence in which oxygen from the atmosphere passes through them. Haldane

Given a list or a diagram of anatomical parts, including the trachea, the bronchial tubes, the lungs, the alveoli, the blood, and the cells, the student indicates the sequence in which carbon dioxide produced in respiration passes through them. Haldane

Given a diagram of anatomical parts involved in breathing and respiration in the human body, the student identifies each part and labels it with its name. Haldane

The student indicates three ways in which the processes of burning and respiration are similar. Haldane

The student indicates at least one way in which the processes of burning and respiration are different. Haldane

When asked to give an explanation of the process of respiration (or to select the best explanation from among three or more suggested explanations), the student states (or selects the one suggested explanation which states) that during the process of respiration oxygen interacts with chemical substances from the food an animal eats and that energy (heat and motion) is released and carbon dioxide and water are produced. Haldane

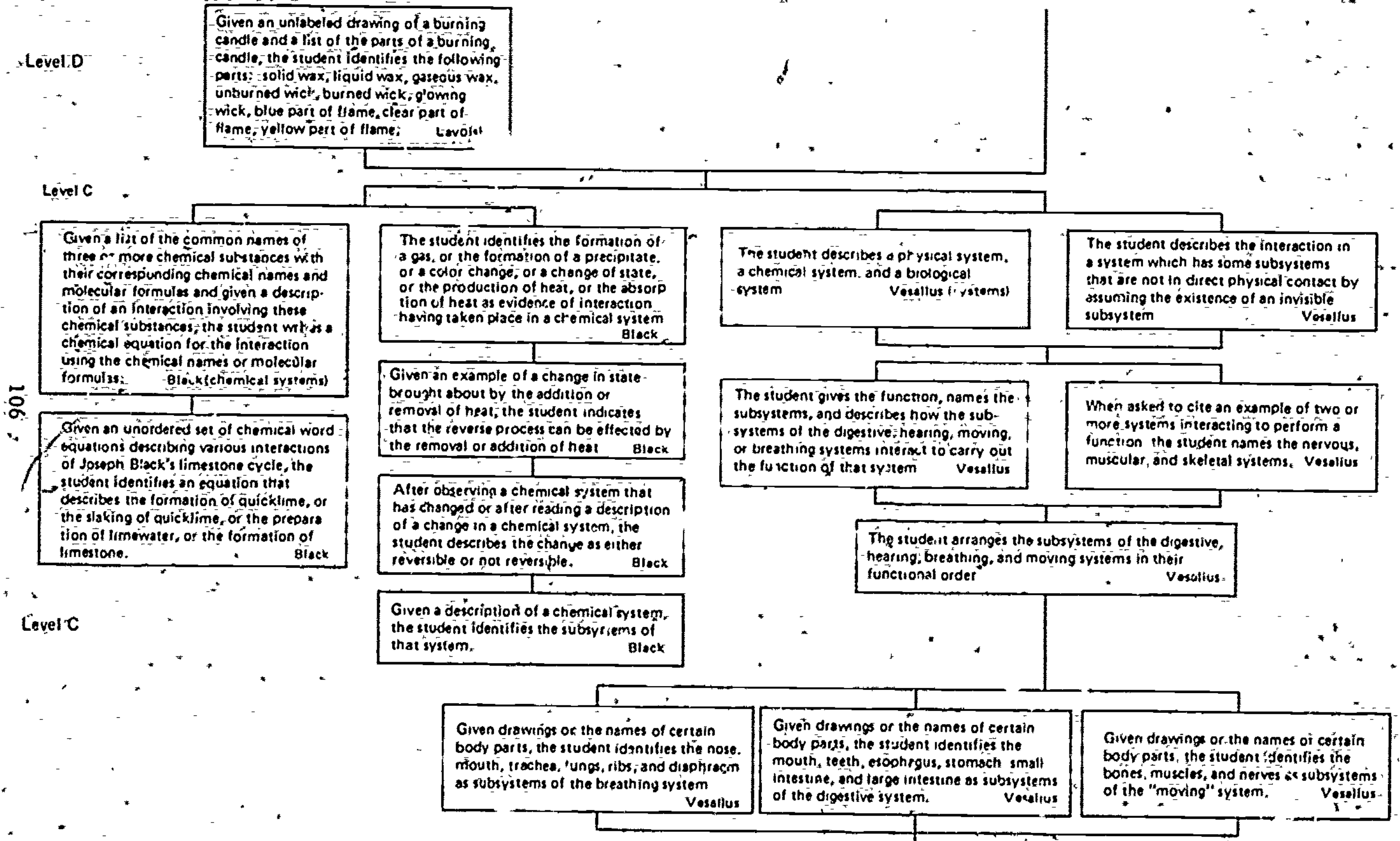
The student writes an equation describing the process of respiration. Haldane

The student applies in a novel situation the concept that oxygen is necessary to maintain animal life. Haldane

The student applies in a novel situation the concept that animals consume oxygen and produce carbon dioxide and water vapor. Haldane

Chart 15 continued on next page.

Chart 15 (Cont'd)



Level D

Given an unlabeled drawing of a burning candle and a list of the parts of a burning candle, the student identifies the following parts: solid wax, liquid wax, gaseous wax, unburned wick, burned wick, glowing wick, blue part of flame, clear part of flame, yellow part of flame. Lavoisi

Level C

Given a list of the common names of three or more chemical substances with their corresponding chemical names and molecular formulas and given a description of an interaction involving these chemical substances, the student writes a chemical equation for the interaction using the chemical names or molecular formulas. Black (chemical systems)

Given an unordered set of chemical word equations describing various interactions of Joseph Black's limestone cycle, the student identifies an equation that describes the formation of quicklime, or the slaking of quicklime, or the preparation of limewater, or the formation of limestone. Black

The student identifies the formation of a gas, or the formation of a precipitate, or a color change, or a change of state, or the production of heat, or the absorption of heat as evidence of interaction having taken place in a chemical system. Black

Given an example of a change in state brought about by the addition or removal of heat, the student indicates that the reverse process can be effected by the removal or addition of heat. Black

After observing a chemical system that has changed or after reading a description of a change in a chemical system, the student describes the change as either reversible or not reversible. Black

Given a description of a chemical system, the student identifies the subsystems of that system. Black

The student describes a physical system, a chemical system, and a biological system. Vesalius (systems)

The student describes the interaction in a system which has some subsystems that are not in direct physical contact by assuming the existence of an invisible subsystem. Vesalius

The student gives the function, names the subsystems, and describes how the subsystems of the digestive, hearing, moving, or breathing systems interact to carry out the function of that system. Vesalius

When asked to cite an example of two or more systems interacting to perform a function, the student names the nervous, muscular, and skeletal systems. Vesalius

The student arranges the subsystems of the digestive, hearing, breathing, and moving systems in their functional order. Vesalius

Level C

Given drawings or the names of certain body parts, the student identifies the nose, mouth, trachea, lungs, ribs, and diaphragm as subsystems of the breathing system. Vesalius

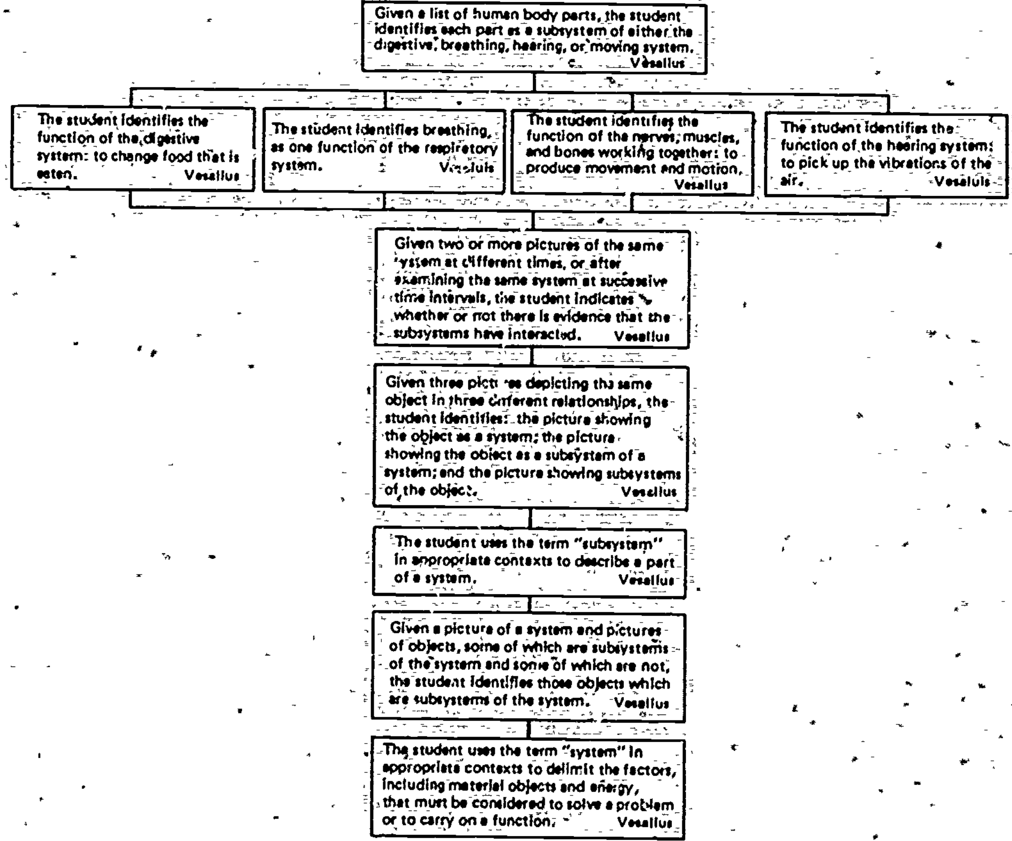
Given drawings or the names of certain body parts, the student identifies the mouth, teeth, esophagus, stomach, small intestine, and large intestine as subsystems of the digestive system. Vesalius

Given drawings or the names of certain body parts, the student identifies the bones, muscles, and nerves as subsystems of the "moving" system. Vesalius

Chart 15 continued on next page.

Chart 15 (Cont'd)

Level C



Given a list of human body parts, the student identifies each part as a subsystem of either the digestive, breathing, hearing, or moving system. [c] Vesalius

The student identifies the function of the digestive system: to change food that is eaten. Vesalius

The student identifies breathing, as one function of the respiratory system. Vesaluis

The student identifies the function of the nerves, muscles, and bones working together: to produce movement and motion. Vesalius

The student identifies the function of the hearing system: to pick up the vibrations of the air. Vesaluis

Given two or more pictures of the same system at different times, or after examining the same system at successive time intervals, the student indicates whether or not there is evidence that the subsystems have interacted. Vesalius

Given three pictures depicting the same object in three different relationships, the student identifies: the picture showing the object as a system; the picture showing the object as a subsystem of a system; and the picture showing subsystems of the object. Vesalius

The student uses the term "subsystem" in appropriate contexts to describe a part of a system. Vesalius

Given a picture of a system and pictures of objects, some of which are subsystems of the system and some of which are not, the student identifies those objects which are subsystems of the system. Vesalius

The student uses the term "system" in appropriate contexts to delimit the factors, including material objects and energy, that must be considered to solve a problem or to carry on a function. Vesalius

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[a] Objective added to developers' objectives.

[b] Objectives abbreviated or two or more objectives combined.