Concept Maps:

A Tool for Use in Biology Teaching

James Stewart
Judith Van Kirk
Richard Rowell

INCREASINGLY BIOLOGISTS ARE DEVELOPING their own courses or limited-scope minicourses. Many of these are primarily conceptual in nature. We would like to share a tool we have developed—the concept map—with other biologists who are developing curricula, planning instruction, or devising evaluative techniques.

Learning Theory and Teaching

Hertig (1976) recently called on biology educators and learning theorists to combine their talents to improve the quality of biology education. In his article, however, Hertig over-dichotomized the differences between the following types of questions: "What biology should we teach?" and "How should we teach it?" on the one hand; and "How do students learn?" on the other. These three questions—what to teach, how to teach, and how students learn—are inextricably intertwined. Techniques and teaching methods should be based upon a solid understanding of how students learn. Helping students learn is, after all, the goal of teachers; therefore, our teaching methods should parallel the learning process.

When biology is viewed as a conceptual system, as we feel it should be, the framework described by Piaget (1972) or Ausubel (1968) is most appropriate. Because Piaget is primarily a developmental psychologist whose emphasis has not been on formal school learning, Ausubel's model that is aimed specifically at the learning which takes place in schools has the most to contribute to a theoretical basis for the learning of biology in school settings.

Ausubel's learning theory is based on the assumption that humans think with concepts; he further postulates that the structure of concept arrangement, which he feels is hierarchical, is an important variable in student learning. In his theory of school learning, as well as in elaborations of it (Novak 1977), concepts and the propositions describing relationships among them are of primary importance. If we accept Ausubel's ideas on the nature of learning, the importance of concepts and their relationships to each other—in teaching and in learning—become obvious. This article describes a tool we have found helpful in the teaching and learning of concepts and the propositions that relate them—the concept map.

A Description of Concept Maps

The concept map (figs. 1, 2, and 3) is a device for representing the conceptual structure of a discipline, or segment of a discipline, in two dimensions. The linear, one-dimensional organizational outline is a traditional way of representing information about a subject. Because of its added relational dimension, however, the

James H. Stewart is assistant professor of science education, University of Wisconsin, Teacher Education Building, 225 North Mills Street, Madison, Wisconsin 53706. He has also taught at Michigan State University (East Lansing), and Tomkins-Cortland Community College (Dryden, New York). Stewart received his B.S. and M.S. degrees from State University College at Geneseo (New York), and was awarded his Ph.D. degree in science education from Cornell University in 1978. Judith Van Kirk received her B.A. degree in English literature from Muskingum College (New Concord, Ohio) in 1969; she expects to receive her M.S. degree in science education in 1979. Van Kirk is the author of a monograph on *The Clinical Interview*, and co-author, with James H. Stewart, of an article on yellow-rumped warblers that appeared in *Kingbird*. She has presented papers at the NSTA and NARST conventions. Richard M. Rowell presently teaches at the Model Secondary School for the Deaf, Galludet College, Washington, D.C. He received his B.A. degree in biochemistry from the State University of New York at Stony Brook in 1970; and his Ph.D. degree in science education from Cornell University in 1978. He has published over 150 natural history articles as weekly features in the *Newfield* (New York) *News*. He is co-author, with Judith Van Kirk, of "Tutorial Modules: How We Keep Humans in Our Instructional Packages." Rowell's hobby is photography, and he is co-director of a consulting group on intercultural education.

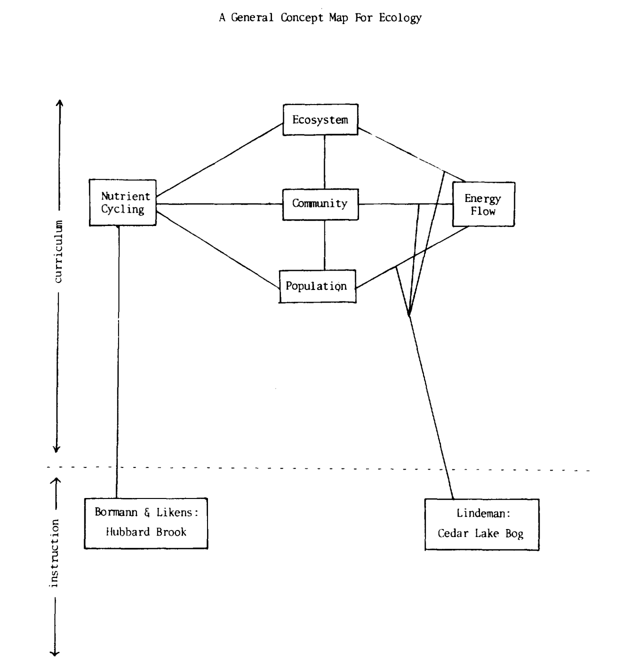

FIGURE 1. A Concept Map of a Portion of Ecology

concept map is much more suitable for representing the propositional relationships among concepts. The construction and use of concept maps implies that in a discipline we find conceptual systems with recognizable patterns of organization. This element of organization is difficult to express in outline form.

An analogy can be drawn between concept maps and roadmaps, with concepts corresponding to cities. An outline will only provide a one-dimensional list of cities. It might list them in some order (by population, north-to-south, or alphabetically, for example); it can demonstrate certain relationships (names of suburbs can be shown as subheadings of cities, for example). But it cannot give the reader an adequate view of the geography of the area it attempts to portray. A nonlinear, two-dimensonal concept map, on the other hand, can be thought of as a scheme including not only cities, but also as a chart describing the major highways (propositions) that link them. Furthermore, not all cities have the same population density; neither will the concepts on a map have identical explanatory density or power. These differences can be easily portrayed on a concept map through the use of the vertical dimension, which usually represents a continuum from general to specific; the most general concepts appear at the top of the map. As the reader of the map proceeds downward, more specific subordinate concepts, with less explanatory power, are encountered. Finally, at the bottom of the map specific, often interchangeable examples are given that will be used to illustrate the concepts above them.

In several senses of the word, the concept map is a flexible tool. How it is constructed, what concepts and relationships are included, and how it is used are matters

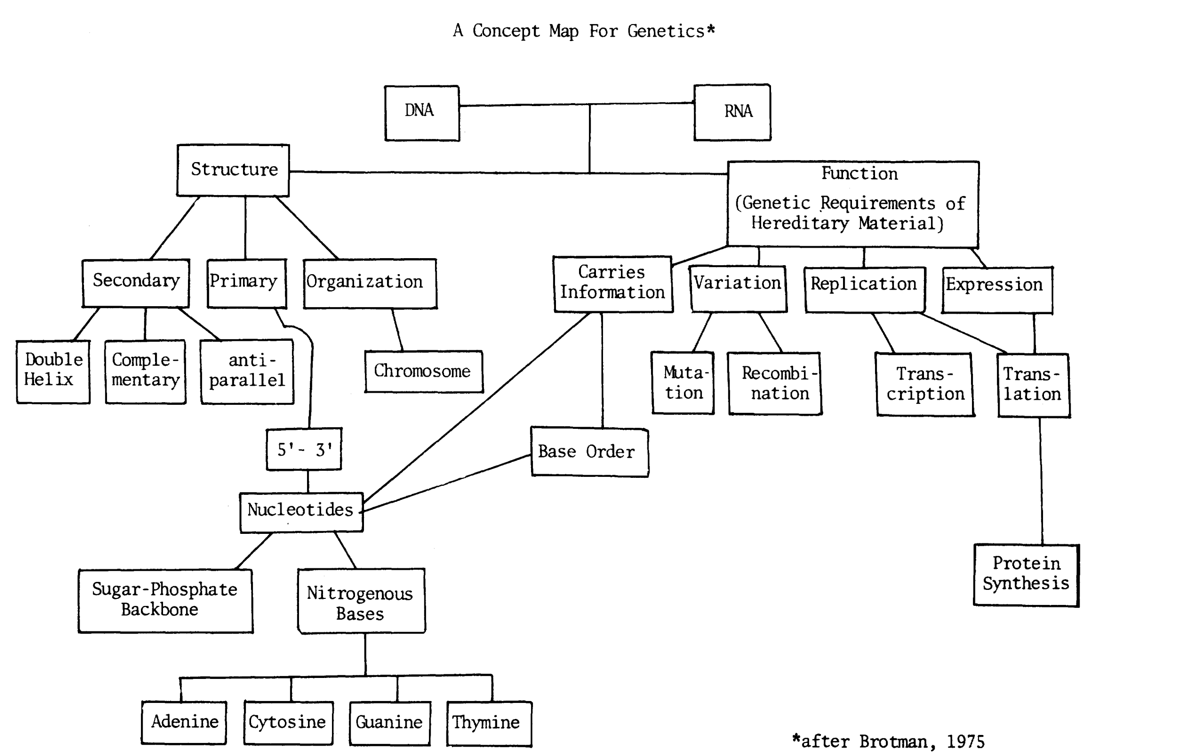

FIGURE 2. A Concept Map for Genetics

left to concept map users, within the constraints imposed by the current structure of biology. The degree of focus can vary considerably. Just as the degree of inclusiveness of the roadways on a map of New York State and an insert of New York City will be different, so will the inclusiveness of the relationships and even concepts themselves as concept maps are developed for different purposes. Some maps (fig. 1) are of low magnification (coarsely focused) but with great "field of view." Others (fig. 2) are of high magnification (finely tuned) with a subsequent decrease in field of view. The maps may act to: (1) identify the major conceptual areas to be covered in a course, unit, or lesson; and (2) briefly describe how these major conceptual areas interrelate to provide overall coherence.

Concept Map Construction

Usually the first step in the preparation of a concept map is to identify the major class concepts, principles, and so on, to be covered, e.g., *ecosystem, producer, second law of thermodynamics,* as illustrated in figure 3. This step is always critical and usually is reduced to the making of judgments by the map constructor, based upon how s/he views the structure of the discipline, as well as the purposes of the map. Gowin (1977) provides guidelines for identifying concepts in a discipline. Once chosen, these initial concepts (or their labels) provide the major landmarks, analogous to the cities and villages on a road map. Keeping the general/specific dimension in mind, the map maker (who ideally is also the biology instructor) proceeds to order the concepts to be taught depending upon several factors, including: the interrelationships among the concepts; the constraints imposed by the course; the background of the instructor; the backgrounds and interests of the students.

As mentioned earlier, the vertical ordering of concepts on a map, using the dimension general to specific, is significant. However, deciding at which level concepts should appear often becomes an exercise in microtopography. Therefore, we feel that it is most important to get the concepts down on the map in a general superordinate-to-subordinate order that is in keeping with the structure of the content to be included in the course. As a practical suggestion, gummed labels or index cards, each with a concept label written on it, can serve as moveable objects that the map maker may stick in place once a useable ordering of the concepts has been developed.

The concept map should now have taken on some meaning (the general/specific dimension) although it does not yet provide much topographical information to a reader. A road map containing only cities shows general geographic relationships but says nothing about how to travel between them easily. The concept map's necessary roadways are the propositions that provide information on relationships, describing connections between

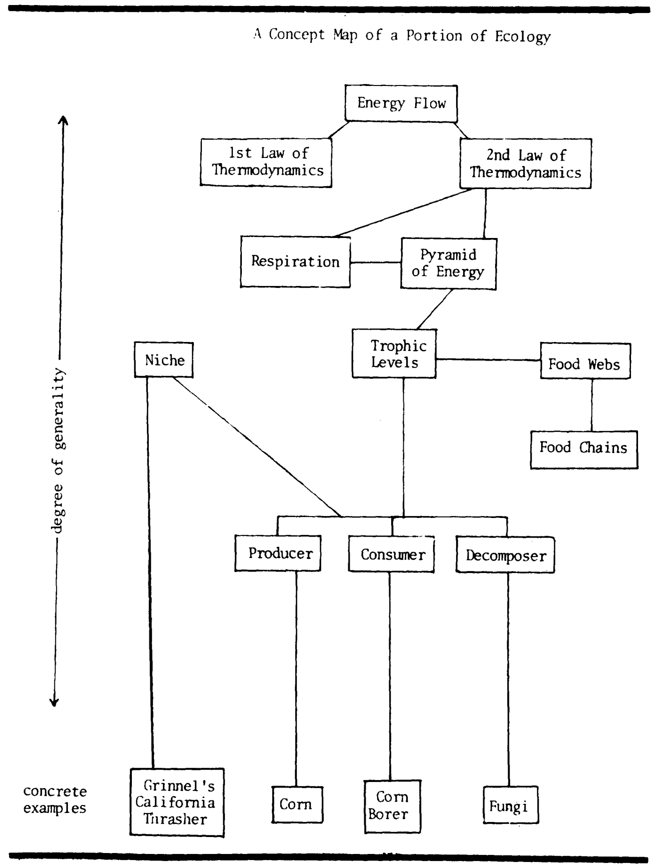

FIGURE 3. A General Concept Map for Ecology

concepts. This is the horizontal dimension of a concept map, something that an organizational outline cannot provide. The next step, then, is to draw relationship lines connecting concepts. In a sense, this is the time when "the structure of the discipline" is made explicit. Though it may not be necessary (or possible) to indicate all relationships, we feel it is essential to include those of major significance on a concept map. Recent research studies have shown the importance of specifying relationships and thus the structure of the curriculum. Rudnitsky and Posner (1976) have found indications that the same botanical "facts" and concepts learned within a different organizational pattern (structure) will lead to the development of different cognitive structures in learners. Another study, in mathematics (Mayer and Greeno 1972), provides evidence that the same concepts, when embedded within different structure, will lead to different cognitive competencies in the learners. Therefore, even if each line is not explicitly defined on paper, its placement should have been justified and must be explainable by the map maker.

For a closer look at the use of relationship lines, refer to the ecology map in figure 3. One relationship between *food webs* and *food chains* is a superset-subset relationship; on the line between *pyramid of energy* and *the second law of thermodynamics* is an explanatory link of a causal nature (the second law explains the inevitability of a pyramidal structure). *Producer, consumer,* and *decomposer* all relate to *niche* because they are general niche categories, but they also relate to *pyramid of energy* in that they compose various trophic levels in an energy pyramid. As a result, *trophic level* is related to *niche.* Many other relationships could be expressed—it is accurate to say that the lines chosen to link concepts on a map are the "superhighways"; the unpaved alternative routes are less likely to be illustrated.

Uses of Concept Maps

Because of the flexibility of concept maps, they can be used in a variety of situations for several different purposes. Three such uses are: (1) as curricular tools; (2) as instructional tools; and (3) as a means of evaluation.

Curricular Uses of Concept Maps. We have found that the Ausubel model of learning emphasizing concept acquisition coupled with a model of curriculum posed by Johnson (1977) is a powerful approach to curriculum development. Within such a framework, concept maps can take on an important role.

In Johnson's view, a curriculum is "a structured series of intended learning outcomes" (ILOs). The ILOs may be affective, cognitive, or psychomotor in nature, although for this paper we have chosen to focus on the cognitive. This does not mean that we feel skill and especially affective ILOs are not appropriate in biology teaching. A most significant contribution of Johnson's model is the distinction he makes between curriculum and instruction. Curricular focus is on selecting and organizing the ILOs: those cognitions, cognitive competencies, skills and affects the curriculum developer most wants students to "possess" as a result of the curriculum. For instance, in ecology, an understanding of the class concepts *trophic level* and *food chain* or the proposition "available energy decreases as one progresses from producer to consumer levels in a food chain" might be desired ILOs. In this case we would want the students to understand the concepts *food chain* and *trophic level* as well as of a particular proposition relating them in a nonarbitrary fashion to the concept of *energy.*

The instructional side of the coin in part asks what examples are the most appropriate to illustrate the chosen concepts and propositions. The appropriateness of the examples might be determined by such factors as time of year, geographic location, and ease of manipulation. The most important determinant should be the backgrounds and interests of the students. Literally thousands of examples may be used to illustrate the various trophic levels in a food chain, and that energy becomes less available as one proceeds "upward" along the chain. The choice of the examples in the Johnson model is an instructional rather than a curricular decision, unless of course the examples are to be learned, and thus are in fact also ILOs.

As educators, we often get bogged down in the "trees" of examples so that our students do not see the conceptual "forest." Johnson's distinction between curriculum (choosing and organizing the concepts and thus selecting ILOs) *vs.* instruction (selecting the instructional, content with which to explicate the concepts) is important. How often in evaluation of students do we test for the knowledge of a particular example without ever coming to grips with the question of whether or not they understand the underlying concepts? It is certainly conceivable that one may know many specific examples without having an understanding of the conceptual interpretations possible for those examples.

Where do concept maps fit into these views of curriculum? Concept maps can be an important tool to focus the attention of the curriculum designer (again, ideally, the instructor) on the teaching of concepts and on the distinction between curricular and instructional content—that is, between content that is intended to be learned *vs.* that which will serve as a vehicle for learning. A completed concept map, including class and major relational concepts, becomes in the Johnson model the cognitive component of the curriculum. Construction of a concept map that portrays structure in a discipline could thus be considered as identical to the task of developing the cognitive components of a curriculum.

Instructional Uses of Concept Maps. When a map includes concrete (instructional) examples to be used to explicate the concepts and propositions to be taught, then it becomes a guide to instruction as well as to curriculum (see figure l). There are a range of possible instructional uses of concept maps.

Bogden (1976) systematically used concept maps in a college-level genetics course at Cornell University. He constructed maps with proportionally large instructional components to correspond to the content of individual lectures in the course, and then used them as a focus for discussion sections. Some students used these sessions and thus the maps as supplements to or substitutes for lectures, laboratories, and readings; others considered the maps valuable review materials that helped to tie different sections of the course together. Some students felt the concept maps were superfluous, but the purpose in using them was for the course instructors to provide an additional pathway to the learning of genetics concepts. Therefore, they did not expect all students to choose the concept map alternative as one they wished to use. Concept maps are only tools, and a functional approach should be taken with them. Their value lies their flexibility and utility, in instruction as well as in curriculum.

A second instructional use of concept maps is to have students construct maps describing what they know about a given subject area. It is recommended that any student asked to do this be well versed in what is expected of him/her and therefore time must be spent beforehand thoroughly introducing students to the concept map idea, including what the instructor wants represented by the two dimensions of the map. It might also be wise to ask only students who have a good grasp of the subject to try and construct maps of it. Constructing a concept map is often a very difficult task for one who knows the discipline well; a student with sketchy knowledge is likely to be overwhelmed and confused by the task if s/he is not properly prepared. On the other hand, the benefits in understanding are likely to be very great to anyone who tries to map a conceptual area with which s/he is familiar—even an "expert" who is compelled to try to represent a discipline in a new way must consciously rethink many assumed relationships and may enrich his/her "feel" for the subject by carrying out a concept mapping exercise.

Concept Maps as Evaluative Tools. We can view the process of evaluation of knowledge as one which ends with the ranking of students for such purposes as assigning grades and helping to determine admission to institutions of higher learning, or pass/fail judgments made upon mastery of a prescribed set of objectives. Many methods are used to this end, and the evaluative uses of concept maps we are about to describe might be as appropriate as any other for the purpose of ranking students. We feel, however, that an at least concurrent aim of evaluation should be the assessment of student knowledge or gaps in knowledge for the purpose of aiding instruction. Students thus become part of a feedback system in which the results of the assessment of their knowledge have curricular and instructional implications.

If we think of evaluation as an assessment of student knowledge, then it is important to focus in test design on what we think of as the conceptual structure of biology. Once again, a concept map, which is considered to be the cognitive component of the curriculum (portraying structure in the subject matter), should be quite useful in evaluating student knowledge of that structure.

Rowell (1976) used concept maps in the area of energy, continuity of life, and properties of matter in trying to gain knowledge of second graders' understandings of those concepts. His evaluative format was a partially structured Piagetian-type interview, and he found that having a concept map in front of him as he interviewed children helped to keep his questions focused on the concepts and relationships in which he was interested.

Bogden (1976) used a genetics concept map to structure an integrative final examination question for a college genetics course. He constructed what he felt was an ideal answer, made a concept map from it, and then mapped student answers. The degree of correspondence between the "ideal" map and student maps was the basis for each student's grade on the question. In using concept maps in this way, however, one must be careful in translating from answers to maps—it is easy to turn this method into a "key word" sort of analysis, and lose track of the substance of answers. Since Bogden in using this sort of evaluative method was actually engaged in ranking as opposed to assessing, any "holes" or missing parts of answers, although impossible to interpret, were still a part of the evaluation and thus the grade.

Conclusions

We are convinced that the concept map can be a valuable tool in curriculum, instruction, and evaluation. We look forward to seeing some of the suggested concept mapping techniques (as well as others) tested and used by others in order to add empirical validity to the idea of concept mapping, because we view these procedures as an important link between learning theory and teaching. We invite biology teachers to produce their own maps and share them with us.

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To predict the future, we need logic; but we also need faith and imagination which can sometimes defy logic itself.

Arthur C. Clarke