

UNIVERSIDAD DE ANTOFAGASTA
FACULTAD DE EDUCACION
Y CIENCIAS HUMANAS
DEPTO. DE EDUCACION

A META-PARADIGMATIC MODEL TO DESIGN BIOLOGY LEARNING MATERIALS

A META-PARADIGMATIC MODEL TO DESIGN BIOLOGY LEARNING MATERIALS

Jaime Sánchez Ilabaca.

Jaime Sánchez Ilabaca

ANTOFAGASTA-CHILE, UNIVERSIDAD DE ANTOFAGASTA, 1989

X ENCUENTRO NACIONAL DE INVESTIGADORES EN EDUCACION, CPEIP, 27-28 y 29 de SEPTIEMBRE 1989

Univ.
Facult.
Ciencias Humanas
Septo. de Educación

7

A META-PARADIGMATIC MODEL TO DESIGN BIOLOGY LEARNING MATERIALS

Jaime Sánchez 41

Diverse views about the way biological education should be approached have been extensively proposed in the literature including emphases on inquiry learning, cognitive psychological models, and interdisciplinary biopsychological theories of learning. These views have focused on specific areas of biology education without giving a more holistic and integrated view of this discipline. Thus some of them have emphasized the philosophical implications of new revolutions in scientific inquiry (BSCS 1963; Brandwein 1971). Others place more emphasis on well established cognitive psychological or biopsychological theories for development of biology curricula (Anderson 1972, 1983; Karplus et al. 1977; Lawson 1975, 1980; Lawson & Renner 1974, 1975; Novak 1977), and communication processes (Anderson 1971, 1972). Other modern approaches have highlighted laboratory teaching by matching cognitive psychological principles, specific inquiry skills, and social aspects of science (Anderson 1976). More recently, extensive efforts have been made to develop both classroom and laboratory tools to enhance cognition and philosophical understandings of science. Among these are concept maps and Vee diagrams to help students to learn how to learn and develop more integrated patterns of thought (Novak & Gowin 1984).

In most of these studies, specific philosophical or learning psychology theories have been applied to design models, tools or strategies to improve the teaching and learning of biology. Several curriculum materials (Bass & Montagur 1972; BSCS 1963, 1980; Karplus et al. 1977; Novak & Gowin 1984; Renner et al. 1976) have been produced based on the application of specific theories of learning, such as those of Piaget (1952, 1966, 1972;), Bruner (1960, 1964), Gagné (1977) and Ausubel (1963). None of them present a clear integration of main constructs involved in science learning to assist teachers in the design and development of tools and strategies to improve their teaching.

This essay spans the void, by presenting an integrated view of biology lesson construction (Sánchez 1985). Specific science inquiry models and cognitive learning theories have been selected and their theoretical rationales synthesized into a model particularly appropriate for development of science teaching strategies. The goal therefore, is to construct a meta-paradigmatic cognitive theory and related science educational models which are particularly applicable to biology lesson construction (Sánchez 1985).

In this context, the views of three major cognitive learning theories have been integrated in this study, namely Jean Piaget's theory of intellectual development, David Ausubel's theory of assimilation and meaningful verbal learning, and Jerome Bruner's theory of cognitive development. The major common points and those specific aspects which can be linked to develop a broader interpretation of cognitive psychology theory have been selected and synthesized to inform curriculum development in biology. Special attention is given to the practical application in biology of the concepts of (1) mental adaptation, assimilation and accommodation derived from Piaget's theory; (2) progressive differentiation and integrative reconciliation in sequential knowledge organization through linkage to prior knowledge as in Ausubel's theory; and (3) the concept of structure of knowledge proposed by Bruner. Let us make a short review of the first two constructs and then discuss the concept of structure in the next section.

Mental adaptation corresponds to the psychological and physical change of behavior as a result of the interaction of processes of mental accommodation and assimilation. Assimilation more particularly, is the application of an established behavior pattern to a familiar or new experience which later can be incorporated into cognitive structures. Accommodation is the tendency to change former behavior patterns in response to experience (Sánchez 1985).

Progressive differentiation and integrative reconciliation can be better understood through examples of concept learning. To enhance meaningful learning, more general and abstract concepts should be presented first to the student followed by progressively differentiated or less abstract content. In this way, a concept is acquired progressively through greater refinement and particularization of the content presented. If we learn the concept of cell, for instance, we first learn its definition, such as "cell is the anatomical, physiological and biochemical unit of all living things". This is certainly an abstract concept. So we go further by stating that three main components of the cell can be distinguished, namely cell membrane, cytoplasm, and nucleus. Later we can say that suspended in the cytoplasm there are cell organelles which explain most cell functioning, so we identify mitochondria, Golgi apparatus, ribosomes, endoplasmic reticulum, centrosome, etc. What we are doing here is to present first the more abstract concept (cell), then progressively differentiate its meaning through explication of subconcepts such as cell membrane, cytoplasm, and nucleus. Ultimately a more fine differentiation is made by discussing the concepts of mitochondria, Golgi apparatus, ribosomes, endoplasmic reticulum, etc. In the course of exposition of the topic some students may not understand fine nuances of meaning as for example confusing cytology with cell biology. Other students may understand these as two completely different concepts, so the teacher may need to relate this "new concept" (cytology) to the previously acquired concept (cell biology) by showing what aspects are synonymous and which are different. This is also called integrative reconciliation.

In addition to the integration of these cognitive constructs to develop the meta-paradigmatic model presented here, some commonplaces among inquiry oriented educational theorists are elucidated and the union of their prescriptive ideas set forth. Thus the inquiry models proposed by a diverse set of scholars, e. i., O. Roger

Anderson(1976), Paul Brandwein(1971), John Dewey (1933), Joseph Schwab(1960a, 1960b, 1964), and Richard Suchman(1966), have been synthesized and integrated to form the meta-paradigmatic model and to set a basis for lesson construction.

THE META-PARADIGMATIC MODEL

STRUCTURE OF BIOLOGY

To achieve an integrated and holistic approach, basic principles of modern biological knowledge organization should be taken into consideration. When knowledge is understood in its broadest context, different degrees of relationships among biological structures can be drawn. In other words, the student comprehends a sufficiently broad context of biological knowledge to mediate synthesis of linking ideas among otherwise apparently isolated units of knowledge. In so doing, different levels of organization among the biological structures can be found. Similarly, the organizational level can be taken as a pattern for a scientifically sound and educationally relevant classificatory organization in biology. This has been labeled as "biology hierarchy", which ranges from a molecular, low level of organization, to a world ecosystem level of biological organization, hence a high level of organization, known as a biome. In other words, a biology hierarchy is a way of organizing biological categories in such a way that lower order ideas are subsumed within higher order ideas. Thus, in the main, the hierarchy of biological organization consists of increasingly inclusive levels such as, molecules, cells, tissues, organs, systems, organisms, population, community, ecosystem and biome. In a subsumptive way, cells include molecules, tissues include cells and molecules, organs include tissues, cells, and molecules, and so on.

The organization of knowledge in hierarchies is proposed by theorists such as Ausubel(1963), and Gagné(1977). But for different reasons, Ausubel recommends that learning is facilitated when broad hence more general information precedes and encompasses subsequent more specific information. Gagné, however, prescribes proceeding from specific units of information to the more general.

In addition to a biological hierarchy, the concept of ideational structure as proposed by Bruner also applies to a discipline as a way of understanding meaningfully how things and ideas within a discipline are related(Bruner 1960). Hence according to this view, the structure of a discipline is composed of the main principles, theories and models that give coherence and meaning to the discipline. This suggests organizing curricula in biological education around relevant themes such as, adaptation, evolution, homeostasis, cell organization, reproduction, etc.

Consider for example the theme of reproduction, which is a potentially broad organizing concept in biology but has not been included fully in earlier projects(BSCS 1963). The pattern given by the reproductive process can be followed throughout the biological hierarchy to give an integrated approach to teaching of biological phenomena. At the molecular level, for instance, nucleic acids (DNA, RNA)follow a reasonably similar pattern of polymer synthesis when duplicating, replicating, transcribing, etc. At a higher level of the biological hierarchy of organization, in a category such as systems, a nearly ubiquitous pattern of sexual reproduction among higher animals is represented by the process of generation of sexual cells by the male and female reproductive apparatus followed by fertilization and continuation of species.

By the same token, even though the usage of a single theme to develop a whole curriculum in biology is highly useful as recommended here, it should be pointed out that too much emphasis on only one theme may not offer a complete picture of the

biological phenomena, losing some aspects that make a broader understanding of this discipline. Hence, it is important to carefully integrate as broad a perspective on the topic as possible within the coherent structure provided by a focal theme.

STRUCTURE OF THE MODEL

Based on the foregoing broad conceptual foundations, Figure 1 shows the structure of the integrative model for biology lesson construction. The structure of the model consists of: (1) Biological topic or contents to be taught, (2) Learning objectives or intended covert and overt student's behavior, (3) Rationale which sets the framework for the content and inquiry emphasis of the lesson and how they are applied to meet the particular cognitive level of the students, (4) Biolesson outline. The latter is the critical part of the model and is divided into three major components: a. The way learning of new ideas should be initiated, called here pre-concept mapping, b. The way learning material should be organized, that is the strategies for introducing and building new ideas, and c. The way new ideas should be integrated to the old ones called here post-concept mapping. Finally an integrative analysis (5) of the lesson is given.

Insert Figure 1 about here

Undoubtedly, the innovative section of the lesson is the biolesson outline. The pre-concept mapping section applies to the use of a cognitive tool so called a "concept map" presented elsewhere by Novak (Novak 1977, 1980, 1981) and Novak and Gowin (Novak & Gowin 1984). This is a way of ordering prior ideas and concepts in a meaningful way and thus of constructing and ordering a mental schema or structure

(e.g. Anderson 1976, p. 80-89) that provides the "cognitive scaffolding" for later learning. Hence, the student comes to understand concepts and their relationships with the ones already ordered in pre-existing mental structures. Guidelines to construct cognitive maps are given by Novak and Gowin (1984), and they can be practiced through classroom interaction, personal interview and group discussion. A top-down sequence of content differentiation is followed as it responds to Ausubelian principles of progressive differentiation and integrative reconciliation. Therefore, students construct meaning and understanding through developing hierarchies to bridge prior and new knowledge to make their learning more related to their personal learning perspective and thus to acquire information in a more meaningful, solid and permanent way.

Once the student's conceptual hierarchy is mentally ordered and meaningfully organized, new related ideas or concepts can be presented with greater precision of acquisition and less confusion. The model introduces the approach of presenting disequilibrating situations to challenge the students to construct their own learning experiences and meanings. The students have to assimilate new learning experiences and then accommodate, reorder and construct them to produce mental equilibration or to set the conditions for mental adaptation (Piaget 1952, 1966, 1972). In the same context, a new meaning is constructed through acting on the experiences, and students play a much more active role, getting control of their own learning experience. For example in the lesson presented below, active student participation is elicited by challenging the students through questioning to explain the pattern of behavior of some species when interacting with other species. The disequilibrating perception is engendered by the entirely different shape of the growth curve when species A and B are placed within the same locale C.

The post-concept mapping analysis corresponds to an integration step in the

development of the biolesson. It is a step that brings all concepts, prior and new ones, together to link new knowledge with the concept maps constructed by the students at the beginning of the lesson. The students will come to realize where this new learning fits into their prior conceptual hierarchy. This can be attained by classroom or group discussion. In so doing, the conceptual linkages will make a profound contribution to enhancing the meaningfulness of their learning as well as to set the mental conditions to start a new learning cycle.

To understand more fully the model, let us analyze an example of constructing a biolesson using this meta-paradigmatic approach.

A BIO-LESSON

BIO-TOPIC: Prey-predator Relationships

- LEARNING OBJECTIVES:
- * Analyze the growth curve for the species A and B
 - * Interpret the growth curve for the species A and B
 - * Construct a prey-predator relationship between species A and B
 - * Predict a similar pattern of behavior for a population which contains similar characteristics of A and B.

RATIONALE:

Content Analysis: The main idea behind this biolesson is to understand an ecological interspecies relationship in which predation is one of the main forms of interaction. In doing so, the concept of prey-predator relationship and their pattern of behavior is to be predicted and extrapolated to other organisms by the students.

Cognitive and Inquiry: By analyzing, interpreting, discovering, and

Emphasis

predicting, the student will have to use high level cognitive skills. A situation of disequilibrium will be created. They will have to reorder prior mental schemas and resolve this situation of disequilibrium.

This is accomplished by associating ideas, discussing, debating and answering challenging questions.

BIOLESSON OUTLINE:

Pre-concept Mapping: The basic ideas required to state anchorage to the new ideas are related to the concept of organism, population, community, energy, primary productivity, etc. The organisms are grouped in populations which, in general, contain the same genetic pool, that is, organisms of similar characteristics that can exchange genes can be grouped in a population. They generally belong to the same species. The number of organisms in a particular area determine the population density. Various organisms of different species constitute a community. In order to maintain an equilibrium in the ecosystem, the organisms of a community interact with each other. As a result of this interaction a flow of energy is produced. This interaction can be positive and negative, that is, beneficial or not beneficial(see Figure 2).

Insert Figure 2 about here

New Ideas: The following activities are suggested:

- * Students discuss with each other about the concepts of organism, population, and community.
- * Students give examples of organisms, population, and community and discuss their relationship in the ecosystem.
- * Students, through discussion, define community, as a group of organisms of different species which interact with each other to maintain a flow of energy.
- * The teacher presents the two curves for population growth of species A and B (see Figure 3).

Insert Figure 3 about here

- * Students analyze the graphs.

[Through questioning and discussion, students will have to determine that the number of individuals increases as the time increases reaching a point where there is no more growth and the population is stable. Basic skills of analyzing graphs are to be employed here, students will have to describe each curve and understand them. If this is not mastered, there is no reason

to start the next step. They should describe these curves in their own terms. Then, if necessary, the teacher can mediate by helping them to describe such a curve in more sophisticated language].

- * Teacher presents a graph that represents the result of putting both organisms A and B in a specific area C (see Figure 4).

Insert Figure 4 about here

- * Students organized in groups analyze the graph
- * Students describe to the class the events occurring through time.

[The teacher plays a key role by asking specific questions that will make the students resolve the disequilibrium produced. S/he may ask questions such as, what happens to species B when species A is growing?, what happens with species A when species B is growing?, can species A and B grow together?, what arguments can you give to explain this situation?, if A grows because it eats B, why does it start decreasing at a certain point?, why, then, is species B growing?. The answer to these questions are to be discussed by the students].

- * As a result of this discussion, students predict the same pattern of growth for other species when the same type of interaction is presented. They may also extend that generalization to other organisms as a pattern for

prey-predator interaction.

Post-concept Mapping: Through a simple example, the students have understood a basic pattern of predation presented in most ecosystems. They have understood that there are periods where the abundance of predators is great. These periods are characterized by a decrease of prey. The amount of prey increases when predators die. Therefore, both populations, A and B interact in such a way that they cannot subsist successfully at the same time in the same ecosystem. This integration can be built in a concept map to relate prior gained concepts and the new concepts as is shown below. (see Figure 5).

Insert Figure 5 about here

INTEGRATIVE ANALYSIS: The emphasis of this biolesson is on storing, perceiving and organizing information. To store this new knowledge, the students will probably have to resolve the incongruities produced when, after presenting two growth curves of species A and B, the students are confronted with a different curve for species A and B in

the same place C. This introduces dissonance. They have to mentally restructure their prior schemes. To attain this, through discussion and questioning, they may assimilate this new understanding and further modifying prior cognitive structures to accommodate this new knowledge to achieve a mental balance. Thus, a new pattern is stored which can help to organize ideas into a rational order to understand the whole pattern given its parts.

DISCUSSION AND IMPLICATIONS

During this decade, there have been modern trends in science teaching to try to merge well established cognitive learning paradigms with current models of scientific inquiry to make their teaching and learning more meaningful, solid and permanent. Eventhough these provocative views have been recommended to introduce a more holistic view of science instruction, the implementation has been limited. The model of lesson construction presented here is intended to bridge this gap between theory and practice in science teaching.

Although special attention has been given to the application of the model to biological content, the broad scope of the model as well as the fine usage of main constructs of well-established cognitive and science learning paradigms, make it suitable to many disciplines, especially those within the natural sciences.

Perhaps the major strength of this model is the synthesis of cognitive and science learning theories as a means of carefully constructing science lessons to facilitate acquisition and organization of science learning materials. On the other hand, the model has its limitations if we consider the fact that the model does not deal directly

with critical constructs in science learning such as reasoning and problem solving, but we must be aware that the structure of the model gives explicit and implicit guidelines to approach these processes more holistically. By the same token, the model will need a complete field testing in different school and college settings to find out its effectiveness in science learning situations. Actually, testing is on its way in Chile. Further research is needed to improve and expand this model.

Clearly, the meta-paradigmatic model described here provides a rich opportunity to focus the learning and teaching of science more broadly with a solid theoretical basis, and to contrive science curricula to help teachers and students to gain greater autonomy in their learning and to develop more integrated patterns of thought.

REFERENCES

- Anderson, O.R. (1971). *Quantitative Analysis of Structure in Teaching*. New York: Teachers College Press.
- Anderson, O.R. (1972). *Teaching Modern Ideas of Biology*. New York: Teachers College Press.
- Anderson, O.R. (1976). *The Experience of Science*. New York: Teachers College Press.
- Anderson, O.R. (1983). A neuromathematical model of human information processing and its application to science content acquisition. *Journal of Research in Science Teaching* 20(7), 603-620.
- Ausubel, D. (1963). *The Psychology of Meaningful Verbal Learning*. New York: Grune and Stratton.
- Bass, J.E., & Montagur, E.J. (1972). Piaget-based sequences of instruction in science. *Science Education* 56(4), 503-512.
- BSCS. (1963). *Biology Teacher Handbook*. New York: John Wiley and Sons, Inc.
- BSCS. (1971). *Biological Science: An Ecological Approach*. Boston: Houghton Mifflin Co.
- BSCS. (1980). *Biology: A Molecular Approach*. Massachusetts: D.C. Heath and Company.
- Brandwein, P.F. (1971). *Substance, Structure, and Style in the Teaching of Science*. New York: Harcourt Brace Jovanovich, Inc.
- Bruner, J.S. (1960). *The Process of Education*. Cambridge, Massachusetts: Harvard University Press.
- Bruner, J.S. (1964). The course of cognitive growth. *American Psychologist* 19(1), 1-15.
- Dewey, J. (1933). *How we Think*. Boston: D.C. Heath and Company.
- Gagné, R. (1977). *The Conditions of Learning* (3rd ed.). New York: Holt, Rinehart and Winston.

- Karplus, R., Lawson, A.E., Wolman, W., Appell, M., Bernoff, R., Rowe, A., Rush, J.J., & Sullivan, F. (1977). *Science Teaching and the Development of Reasoning: Biology*. California: The Reagent of the University of California.
- Lawson, A.E. (1975). Developing formal thought through biology teaching. *American Biology Teacher* 37(7), 411-419.
- Lawson, A.E. (Ed.). (1980). *The Psychology of Teaching for Thinking and Creativity*. AETS Yearbook, Columbus Ohio: ERIC/SMEAC.
- Lawson, A.E., & Renner, J.W. (1974). A quantitative analysis of responses to piagetian tasks and its implications for curriculum. *Science Education* 58(4), 454-559.
- Lawson, A.E., & Renner, J.W. (1975). Piagetian theory and biology teaching. *American Biology Teacher* 37(6), 336-343.
- Novak, J. (1977). *A Theory of Education*. Ithaca New York: Cornell University Press.
- Novak, J. (1980). Learning theory applied to the biology classroom. *American Biology Teacher* 42(50), 280-285.
- Novak, J. (1981). Applying learning psychology and philosophy of science to biology teaching. *American Biology Teacher* 43(10), 12-20.
- Novak, J. & Gowin, B. (1984). *Learning How to Learn* New York: Cambridge University Press.
- Piaget, J. (1952). *Origins of Intelligence in Children*. New York: International Universities, 1952.
- Piaget, J. (1966). *Psychology of Intelligence*. Totowa New Jersey: Littlefield Adams Co.
- Piaget, J. (1972). Intellectual evolution from adolescence to adulthood. *Human Development* 15(1), 1-12.
- Renner, J., D. Stafford, A., Lawson, J., McKinnon, F., & Kellog, D. (1976). *Research Teaching and Learning with Piagetian Model*. Oklahoma: University of Oklahoma Press.

- Sánchez, J. (1986). A model of biology lesson design based on a sythesis of modern learning theory and science inquiry techniques. *Dissertation Abstracts International* 46.
- Schwab, J. (1960a). What do the scientists do. *Behavioral Science* 5(1), 1-27.
- Schwab, J. (1960b). Inquiry, the science teacher, and the education. *The School Review* 18(2), 176-195.
- Schwab, J. (1964). The structure of the natural science." In G. W. Ford, & Pugno, L. (Eds.), *The Structure of Knowledge and the Curriculum*. Chicago: Rand Mc Nally Co.
- Suchman, J. (1966). A model for analysis of inquiry." In H. Klausmeir, & Hans, C. (Eds.), *Analysis of Concept Learning*. New York: Academic Press.

Figure 1. Model of Biology lesson construction. After stating the learning objectives, a rationale to stress the main content, cognitive and inquiry emphasis of the lesson is explicitly discussed. The lesson starts pre-organizing prior concepts through mapping, then new ideas are presented through presenting disequilibrating situations to challenge mental adaptation and finally ending with the integration of new and old concepts through mapping. An explicit integration of the lesson is also suggested.

BIO-TOPIC

LEARNING OBJECTIVE

	CONTENT EMPHASIS
--	------------------

RATIONALE	
-----------	--

	COGNITIVE AND INQUIRY EMPHASIS
--	--------------------------------

	PRE-CONCEPT MAPPING
--	---------------------

BIOLESSON OUTLINE	
-------------------	--

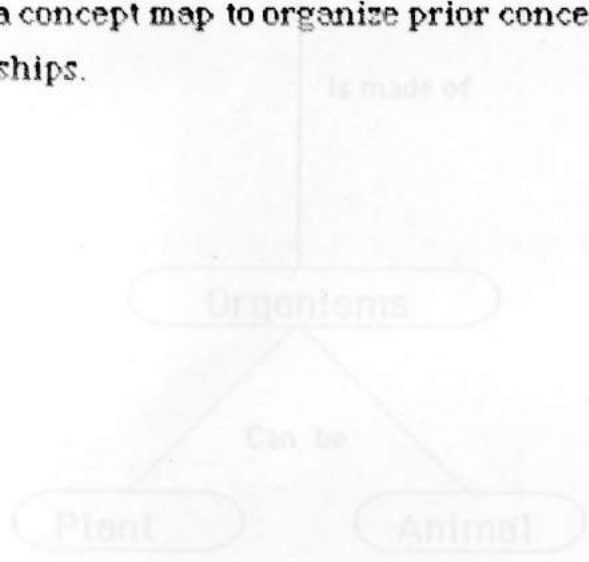
	NEW IDEAS OR CONCEPTS
--	-----------------------

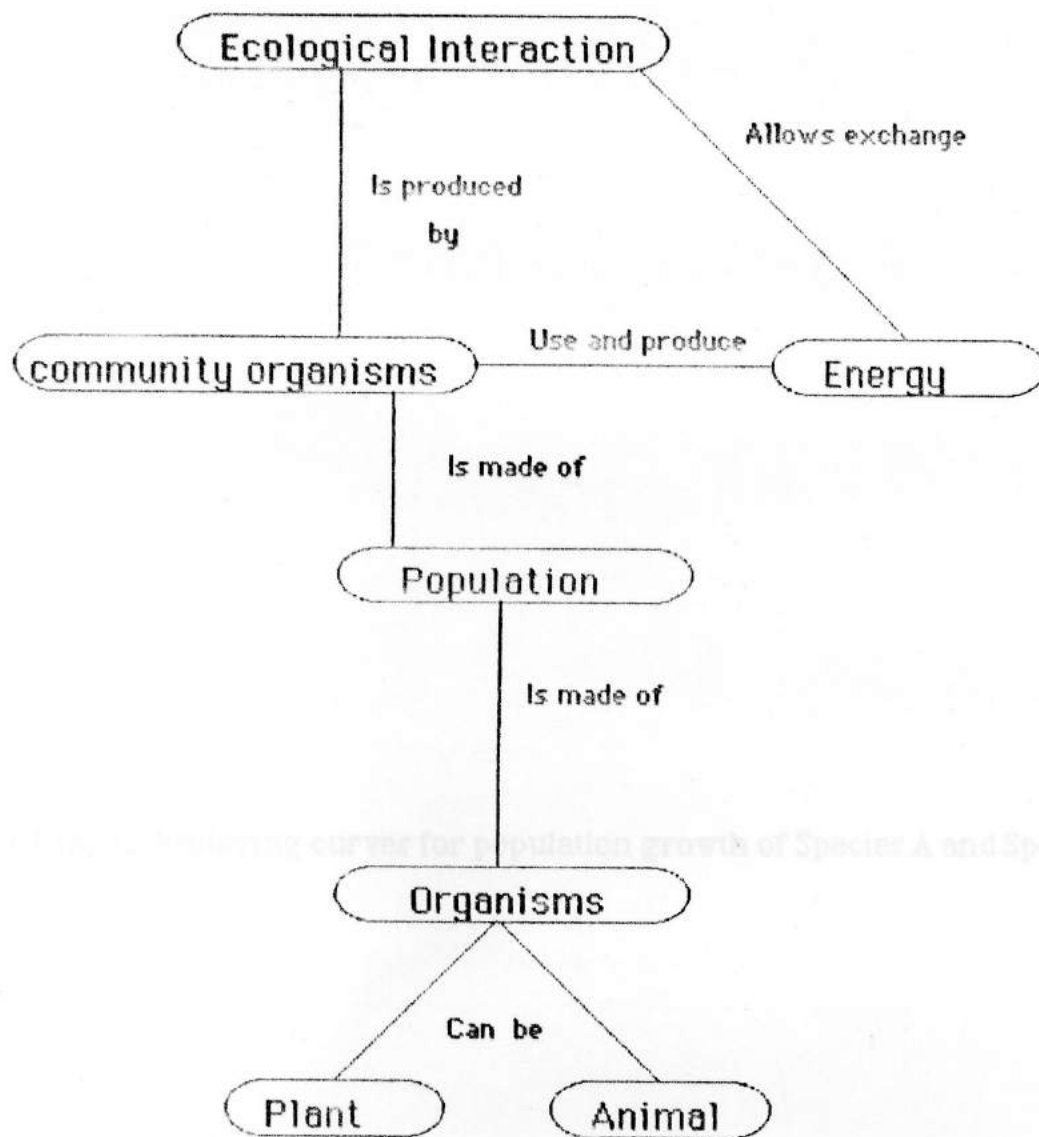
	POST-CONCEPT MAPPING
--	----------------------

INTEGRATIVE ANALYSIS



Figure 2. Example of a concept map to organize prior concepts related to interspecies relationships.





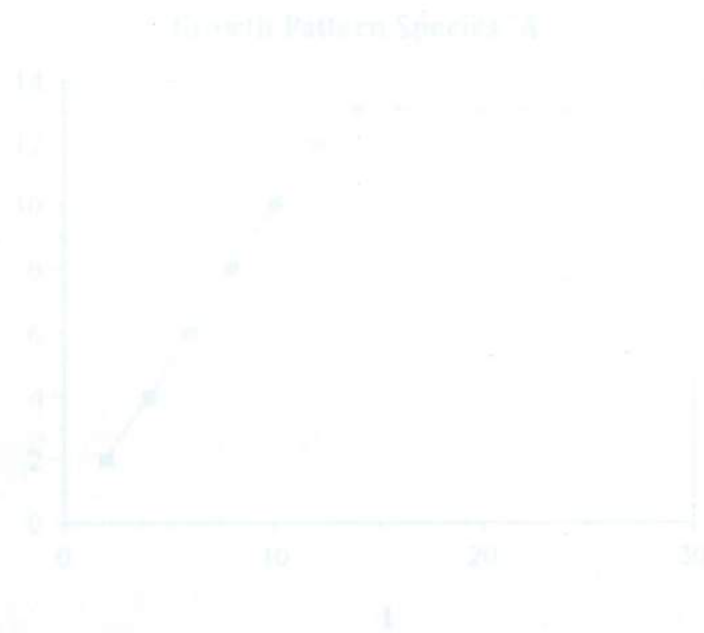
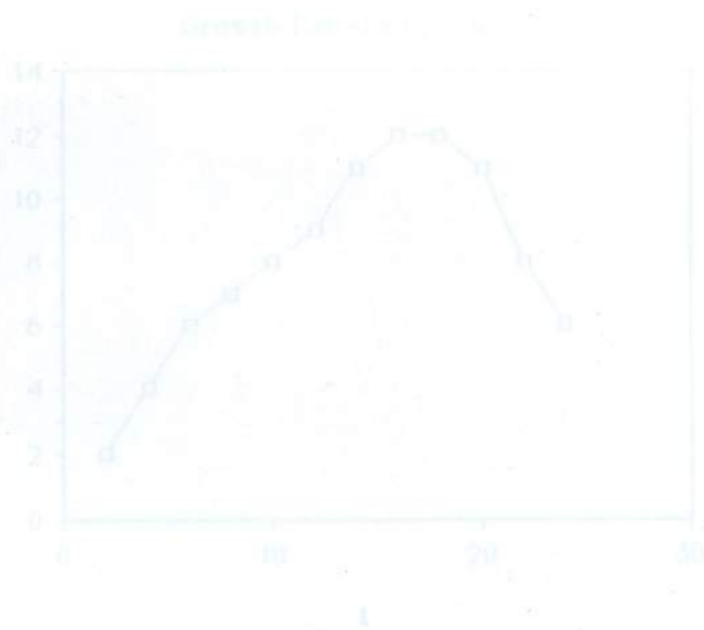


Figure 3. Graphs displaying curves for population growth of Species A and Species B



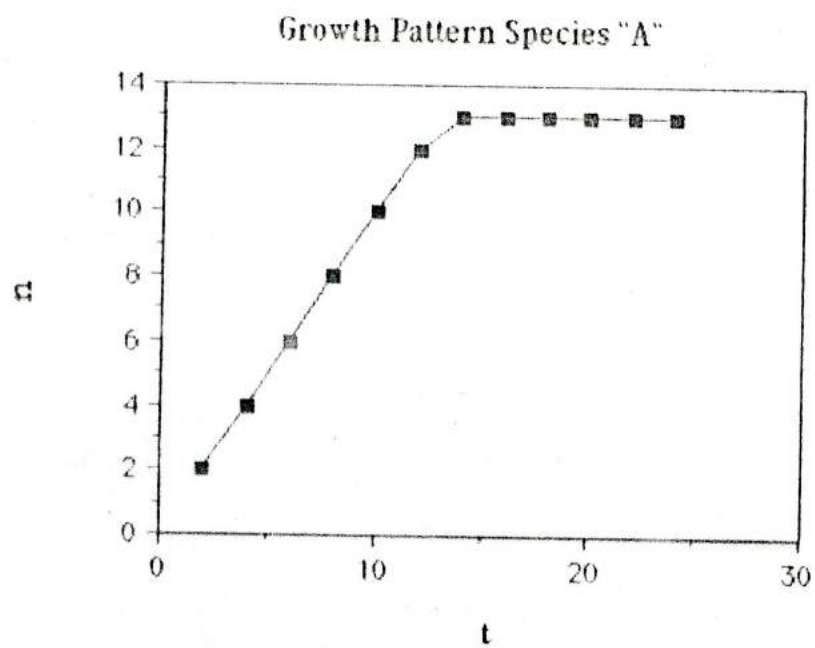


Figure 4. Interaction of Species A and Species B, showing population growth and its implications for population growth.

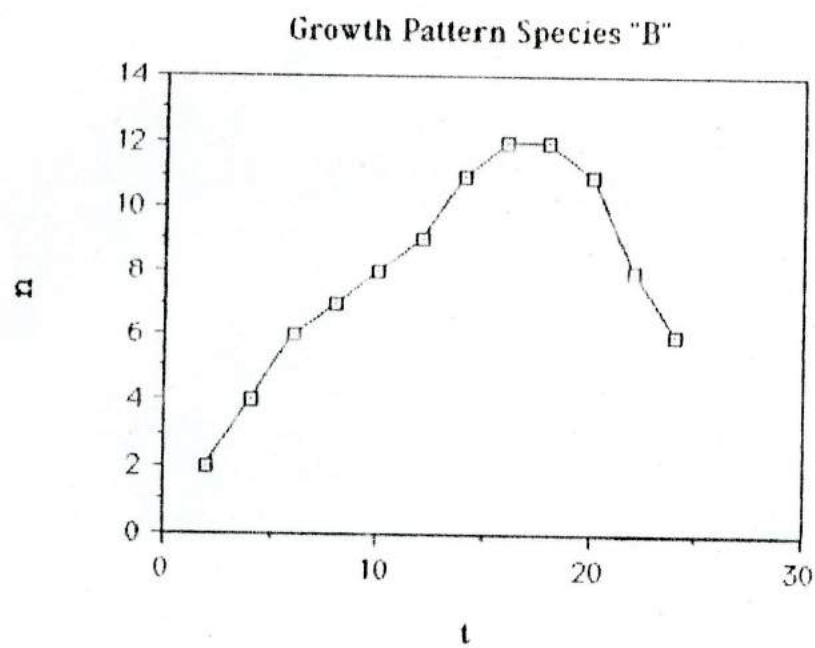


Figure 4. Interaction of Species A and Species B, showing prey-predator relationship and its implications for population growth



Growth Pattern Species "A" and "B"

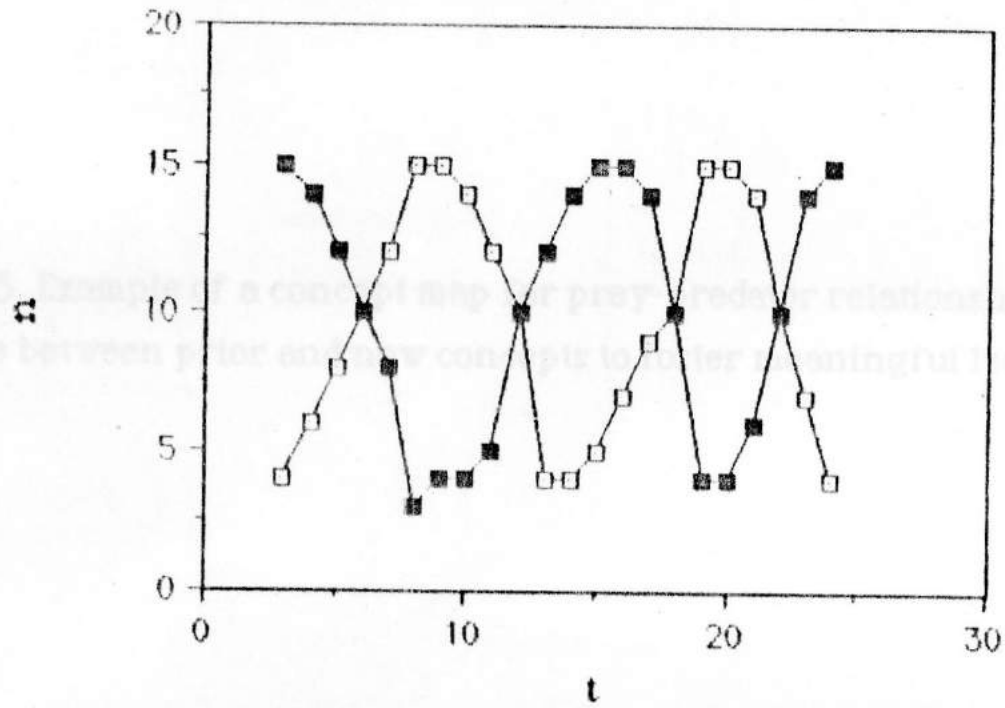


Figure 5. Example of a concept map for prey-predator relationship, showing the linkage between prior and new concepts to foster meaningful learning.



