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ABSTRACT

This study suggests the use of a systemic process approach to the analysis of students' understanding of biological systems. A unified model was employed to enable the capture of the dynamic nature of biological processes and phenomena. The study is based on the integration of two conceptual frameworks, one related to systems and the other to the ontological nature of processes. The model was developed through the study of students' understanding of energy in the biological context as it resulted from a curricular unit on energy that was based on a qualitative, thermodynamic approach. Four independent interrelationships were studied: (1) within biological processes; (2) between processes; (3) between processes and general biological phenomena; and (4) between general biological phenomena and general theoretical frameworks. Analysis of the data provides a deeper understanding of students' conceptions and focuses on the more important issues of biological systems. Contains 14 references. (Author/DDR)

A Systemic Process Approach To the Analysis of Biological Phenomena

by
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A Systemic Process Approach to the Analysis of Biological Phenomena

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The present study suggests a systemic process approach to the analysis of students' understanding of biological systems. It is a unified model that enables to capture the dynamic nature of biological processes and phenomena. It is based on the integration of two conceptual frameworks; one that relates to systems and the other to the ontological nature of processes.

The model was developed through the study of students understanding of energy in the biological context, as it resulted from a curricular unit on energy that was based on a qualitative thermodynamic approach. Four, not necessarily hierarchical, independent interrelationships were studied: (a). Within biological processes; (b). Between processes; (c). Between process(es) and general biological phenomena; (d). Between general biological phenomena and general theoretical frameworks.

The present study suggests a systemic process approach to the analysis of students' understanding of biological systems. It is a unified model that enables to capture the dynamic nature of biological processes and phenomena. It is based on the integration of two conceptual frameworks; one that relates to systems and the other to the ontological nature of processes.

Senge (1990) defined systems analysis as "a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots'". By this definition various possible interactions among components, and the patterns of change - processes, are the keys for systemic understanding. The other conceptual framework is the ontological categorization suggested by Chi et al. (Chi & Slotta 1993, Chi, Slotta & Leeuw 1994). These authors categorize all the entities in the world into three distinct ontological categories: Matter (or Things), Processes and Mental States. They claim that entities within each category differ by their basic nature, and are described and explained by different operational sets. They assert that transfer of concepts from one ontological tree onto another, may cause difficulties in learning and understanding; e.g. the use of Matter based language to describe entities from the

Processes category is claimed to be one of the main obstacles in understanding abstract scientific concepts. The analysis of the Processes category is regarded as their major innovative contribution and the most critical in understanding scientific concepts. The category of Processes is further subdivided into three sub-categories: 1). Procedures, which are "carried out", i.e. sequential processes, 2) Events, which are "caused by" processes, and 3) Constraint-based interactions, which are acausal interactions and are applicable beyond a specific subject. Constraint-based interactions such as gravitational force, light or evolution "are determined by a known or knowable set of constraints....and...are not confined within disciplinary boundaries" (Chi, Slotta and Leeuw 1994, p:31,32).

Senge advocates focusing on patterns of change, but he does not prescribe the nature of the language to be used when relating to such processes. Chi et al. advocate that the language to be used should be distinct to processes only, and should reflect the different organizational levels beyond disciplinary boundaries. The synthesis between these two lines of thought, offers a model that can be instrumental in understanding the dynamic nature of biological systems, from molecular processes as well as global biological and environmental issues.

Background

Students' difficulties in conceiving the interrelational nature of biological systems were documented in the research literature. Chi et al. (1994a) report about students having difficulties in making connections among local and system-wide features of the human circulatory system. Songer & Mintzes (1994), refer to the problematic understanding of the relations between events of cellular respiration and various biological phenomena such as breathing, circulation, wine-making, and ecology. Hogan & Fisherkeller (1996) found difficulties in the ability to relate photosynthesis or decomposition of matter to the nutrient cycle. Griffith & Grant (1985) reported students' misconceptions in the analysis of food webs. They described problems in perceiving the dynamic relations among non-adjacent habitants of the same web, i.e. a failure in analysis of interrelated nets of the population.

The model we suggest includes four, not necessarily hierarchical, independent interrelationships:

1. Interrelations within a biological process - interactions within a single process; e.g. photosynthesis.
2. Interrelations between processes - grasping the interactions between processes, e.g. catabolic and anabolic processes.
3. Interrelations between process(es) and a general biological phenomena; e.g. cellular respiration and thermo-regulation.
4. Interrelations between general biological phenomena and scientific theoretical frameworks; e.g. reproduction, increase of order in the living world, and thermodynamic principles.

The model was developed for the analysis of students' understanding of energy in biological context. The studied curricular unit on energy was based on a qualitative thermodynamic approach. The latter was developed on the basis of research that supported a thermodynamic approach, specifically in context of the Second Law, for the enhancement of students' understanding of energy and biology (Solomon 1987, Gayford 1986, Ross 1988, Kesidou & Duit 1993, Duit & Haeussler 1994, Barak, Gorodetsky & Chipman 1997). A processes systemic model for monitoring students' understanding as developed through this curricular unit seemed to be suitable, as thermodynamics is systemic by its nature and implies process-based procedures for the understanding of systemic behavior.

Method

The research examined the influence of the Thermodynamics - Energy curricular unit (Barak 1995) on students' understanding of energy and the conception of biology. The unit was designed to last about 45 hours.

The experimental group was composed of 161 tenth graders that studied the newly developed unit. Students` conception of energy and biology were tested by a questionnaire that some of its questions demanded comprehensive written answers. Eighteen students of the experimental group were interviewed. The interviews related to the understanding of energy, conception of biology and their attitudes towards the new unit. Each interview lasted about 45 minutes and was conducted by a research assistant who had not been involved in teaching nor in research.

The results presented in this work are based on a qualitative analysis of students' written answers and interviews. The examples included in this work (excluding photosynthesis) were not part of the curricular unit.

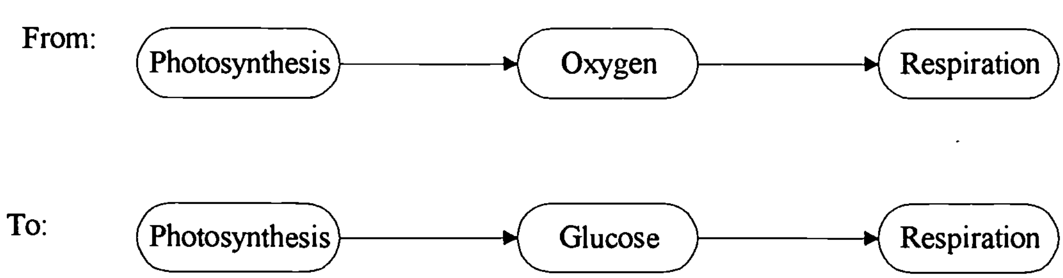
Results and discussion

The results indicated that the study of the curricular unit did impose a significant change towards a more scientifically accepted conception of energy and biology (Barak 1996). In this presentation we wish to further explicate how this change in students' conceptions is actually a change in understanding the nature of systemic processes.

1.Interrelations within biological processes.

Students' understanding of a single process ranged from focus on reactants and products to the understanding of intermediate phases and their meaning to the process as a whole. Regarding the process of photosynthesis, the results reflected a shift from focusing on oxygen as the main end product, towards understanding the importance of glucose production (Barak 1996).

The qualitative analysis revealed that answers that referred to end products did not actually reflect different procedures of analysis. The change appeared to be a shift from emphasis on one end product to another, as can be demonstrated in the following flow diagrams:



Scheme 1: Photosynthesis represented by end products

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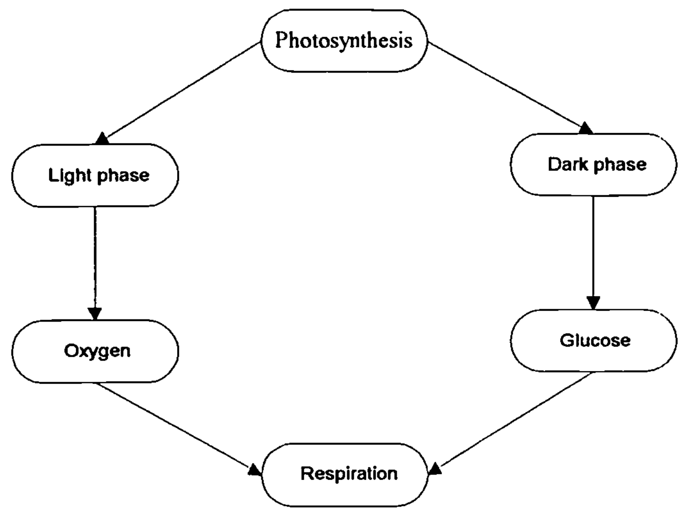
On the other hand students who considered the intermediate phases provided explanations which were simultaneously based on both end products, tying up both processes, as is demonstrated in the next example:



Scheme 2: Photosynthesis represented by intermediate phases

The ability to consider the sub-processes between reactants and products enabled the inclusion of both aspects of the process. Relating to the intermediate phases and the interrelations resulted not only in a better understanding, but it also reflects the comprehension of the systemic nature of the process and its relation to the living world.

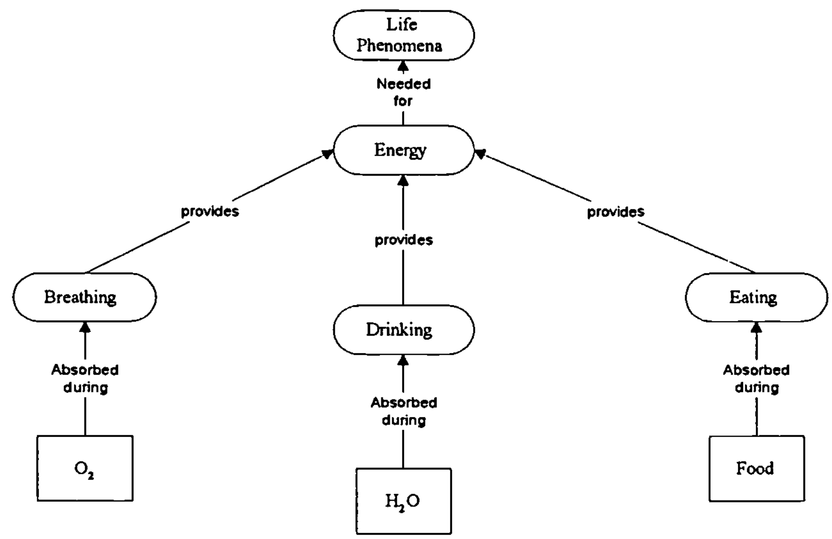
2. Interrelations between processes.

Students' understanding of the relations between processes could be analyzed on a continuum from concentrating on a particular process to a conception that interrelates among various processes. Their conception of energy resources for the human body ranged from focus on the importance of "food we eat", "the water we drink" and "the oxygen we breath" as particular and independent routes that provide energy to the human body.

"We get the energy we need from the food we eat that converts to energy, from water that is also converted to energy, and from oxygen that during breathing is also converted to energy."

"We do not have only one source of energy, but many: food, water and oxygen."

These answers reflect an additive and matter-based conception of the relations between processes. Scheme 3 demonstrates students conception of breathing, drinking and eating as three autonomous processes that provide the energy needed for life sustainment.



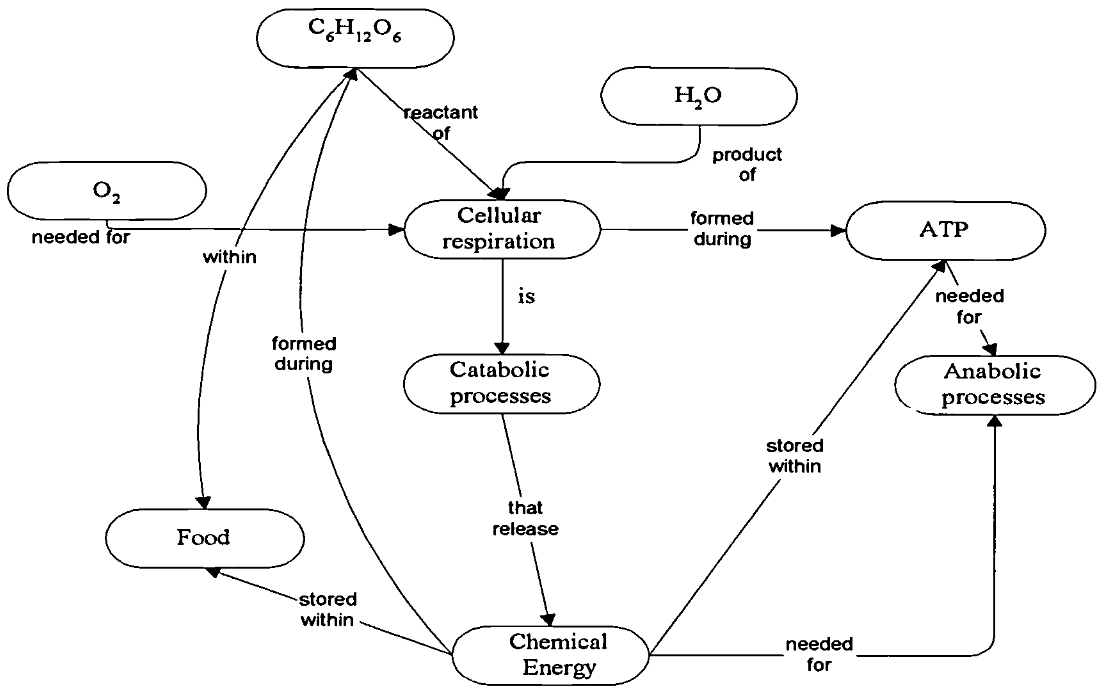
Scheme 3: Students' particular conception of energy resources for life.

On the other end of the continuum was the conception that related to the interrelations among various processes that resulted from the incorporation of the physiological functions. Answers within this category explained the relations between food, water and oxygen on the basis of catabolic and anabolic processes that accompany food degradation and cellular respiration.

" Chemical energy comes from the food we eat. The oxygen is needed for the respiration process during which the energy is released, but it is not the source of energy."

"... the food is decomposed through catabolic processes. The energy that was released is stored within ATP molecules, that are decomposed during anabolic processes."

"... During food degradation energy needed for our metabolism is released, we invest this energy during anabolic processes within the body".



Scheme 4: Students' integrated conception regarding the energy resources for life

Scheme 4, presents a conception that integrates between catabolic and anabolic processes, where cellular respiration is the major function in providing the energy needed for the living body.

The conception illustrated in scheme 4 relates to the interrelations among the various processes ignoring external dividing boundaries. While the language used by the first group was matter-based, the answers provided by the later are characterized by a process based approach. It reflects the understanding of the dynamic complexity of the relationships between the various processes. It reflects a more comprehensive systemic understanding of the human body.

3.Interrelations between process(es) and general biological phenomena.

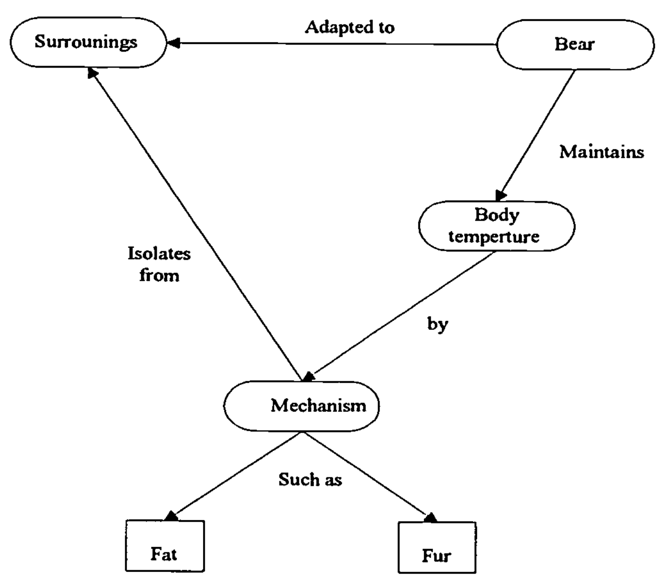
One of the test questions referred to the issue of maintaining a constant temperature by the polar bear as opposed to a metal cube. Students' answers can be categorized on the continuum from referring to phenomenological - concrete features such as fat and fur as being responsible, to discussions based on thermo - regulatory mechanisms of living organisms. Those that based their answers on phenomenological - concrete features of the bear, failed to give an accurate explanation of the phenomena.

"Polar bear is adapted for life in the snow, so it developed protection mechanisms".

"The mechanism is the fur and fat that keep the body temperature, the metal block does not have such a mechanism".

"The polar bear was created for life in the snow. Its' fat creates isolation and it does not lose heat to the surrounding"

These answers rely on phenomenological observations (fat and fur) or teleological explanations (the polar bear is meant to live in the snow). This conception is illustrated in scheme 5.



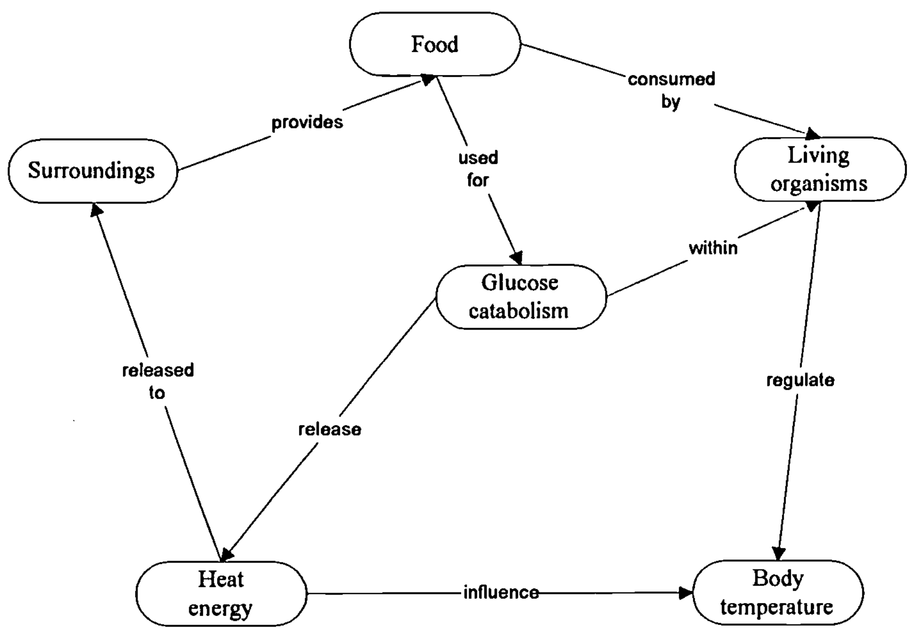
Scheme 5: Students' phenomenological - concrete conception of heat sustainment by the bear

Scheme 5 describes the living body and it's surrounding as isolated entities. The concept `mechanism` in these responses stems from the teleological conception of explanations, which needs no further elaboration. It is known that there are functions such as maintaining body temperature or adapting the living organisms to their surrounding. The main difference between the conception presented above and the following one is a shift to a systemic approach based on the analysis of biological phenomena within a general scientific frame.

" Part of the energy released during glucose catabolism serves to maintain body temperature."

"Living organisms release heat to the environment and consume energy (food), in order to regulate their body temp.

This conception is illustrated in Scheme 6.



Scheme 6: Students' conception of heat sustainment within a general theoretical framework.

Scheme 6 represents the ability to view phenomena by attending to the processes rather than to specific concrete examples. The term mechanism is explicated through the analysis of interrelations between temperature maintenance within the general framework of physiological explanations regarding the living body in its surroundings. This conception reflects the use of processes language rather than materials terms in explanations.

4. Interrelations between general biological phenomena and scientific theoretical frameworks.

The recognition that the principles governing the inanimate world are relevant for explaining the living phenomena is not common to many students (Barak, Gorodetsky & Chipman 1997). An illustrative statement is:

"The issues of chromosomes, enzymes, cell divisions etc. has nothing to do with the laws of nature".

This conception represents a division between biological phenomena and the non-living world as to their compliance to the same theoretical principles of nature. Some of students' answers to the question of growth of material during cell divisions were of this nature:

"That is how the cell functions"

"... those processes are producing matter"

The other group of answers related to the relations between biological phenomena and general laws of nature:

"The laws of nature are not according to materials and disciplines."

"The basis for laws regarding Physics, Chemistry and Biology is the same, since it is the same world."

Or a more sophisticated answer on the cell level:

"There are out side material resources, the division depends on energy consumption. It is not like getting something out of nothing."

"The cell is an open system it always gets materials from the out side."

One of the obstacles in students` understanding of biological systems stems from viewing the later as closed and self-contained (Barak, Gorodetsky & Chipman 1997). The explanations that focused on particular phenomena referred to the living world as an isolated system and they also neglected relations with other phenomena. An enclaved issue, by its' nature, calls for a matter-based language of description, whereas an explanation that refers to relations overpasses boundaries and leads to the understanding of the dynamic and open nature of the system.

Concluding remarks

The model and the supporting examples presented in this presentation referred to systems analysis based on processes rather than components or material constituents. Students` success to analyze systems, they were not exposed to during the formal studies, indicated the development of a process based scheme for the analysis of interrelations.

Indeed, some of the answers reflected a specific case based description of unique specific constituents. In these cases the borders of the system were determined by each particular observation and the answers reflected a matter-based approach regarding the understanding of biological systems. However, some of the answers were based on detailed analysis of the interrelations. The boundaries in these explanations were flexible and stretched to the limits of students' knowledge. These explanations reflected a process-oriented approach that could be analyzed within the four types suggested for the analysis of interrelations. These were expressed in all the categories of life; between products and reactants within a process, between processes within the living organism, between the living organism and its surroundings and between the living and non-living worlds.

This analysis provided us a deeper understanding of students' conceptions. It focuses on the more important issues of biological systems, which are the interrelated processes, rather than on descriptions of isolated issues. Even more, it integrates biological phenomena within a wider conception of processes in the world, as processes are not constrained to a specific system.

We believe that teaching within this framework has the potential to overcome some of the indicated problems in understanding biological systems, and promote a more meaningful and wider conception of biology and the sciences in general.

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