

Articles

An Advance Organizer for Teaching Bacterial Metabolism

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The metabolic versatility of bacteria is a source of learning difficulty for students in classical microbiology courses. To facilitate the learning process, the authors developed an advance organizer. It consists of a set of six diagrams of metabolic pathways describing the basic living requirements of several types of bacteria: energy, carbon sources, and oxidizable substrates that provide electrons for reductive biosyntheses. The students are presented with the six diagrams and at the same time with one problem that must be resolved using solely the set of diagrams, with no access to any textbook. This procedure aims at developing the skills necessary to analyze different (and perhaps more complex) metabolic processes than those represented by the diagrams.

Keywords: Advance organizer, bacterial metabolism, metabolic pathways.

One of the most remarkable features of bacteria is their metabolic versatility [1]. This characteristic allows bacteria to colonize many different types of environments, including those with or without organic matter or oxygen or in the presence or absence of light [2]. The great diversity of niches occupied by bacteria is a result of their ability to oxidize many different substrates, to utilize different final acceptors in their electron transport chains, and to carry out different types of photosynthesis. However, all these different alternatives are adaptive variations of the means to fulfill the same basic requirements necessary to all living organisms: energy, carbon sources, and oxidizable substrates that provide electrons to be used in their reductive biosyntheses.

The understanding of this reductionism is by no means trivial to the students enrolled in courses of microbiology. Indeed, only studies of biochemical metabolic pathways, either based on the mammal, heterotrophic model of metabolism or on the phototrophic model typical of higher plants, are familiar to most students. However, those examples constitute specific cases where only a limited number of organic compounds are oxidized and where oxygen is the final electron acceptor (mammals) or where light is the source of energy, CO₂ the carbon source, and water the oxidizable substrate (plants). Those same metabolic models are also found in bacteria, but prokaryote cells also employ other metabolic processes [3], which enable them to colonize a great variety of environmental niches, endowing them with an important ecological role and with the capacity to transform nature.

In traditional microbiology curricula, it is common prac-

tice to present the different metabolic types found in bacteria as described in textbooks in an independent, nonintegrated manner. Our experience shows that this approach makes it difficult to understand unfamiliar processes, frequently leading students to learn by memorizing, denying them the opportunity to see the basic features that are common to different types of metabolism.

We describe in this article the development of a tool and the implementation of a method designed to establish the general principles underlying the most common types of metabolism before detailing each of them and presenting their specific features. This approach deals only with the previously mentioned basic requirements of bacteria (both carbon and energy sources) without taking into account sources of nitrogen, sulfur, and micronutrients.

This type of teaching tool, defined by Ausubel [4] as an "advance organizer," is an instructional aid to be presented to the students prior to the learning material. An advance organizer is a cognitive strategy that provides a bridge that links the known to the unknown, making the new knowledge more meaningful to the learner and giving him/her a preview of what is to come in the instruction. Several tools, namely graphics, diagrams, concept maps, and even oral presentations, can fulfill this requirement. The most important point is that general ideas of a subject should be presented first and then progressively differentiated in terms of details and specificity. To reach the status of advance organizer, the instrument must present a high degree of inclusiveness and generalization and little factual information.

In short, the organizer fulfills two fundamental roles in the teaching/learning process, namely 1) to provide a scaffold to subsequent learning and 2) to allow students to predict the learning that lies ahead. As an advance organizer, it should not be used solely to introduce the subject of metabolism.

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Quite the opposite, it must be a reference to be used all along the instructional process at the same time that the details of the processes it anticipates are presented.

Unlike overviews and summaries, advance organizers have been poorly utilized in the teaching of experimental sciences, despite the benefits provided by their use [5–7]. Some of the few instances where they have been used involve precisely the teaching of microbiology to medical students [5] and the study of metabolic pathways in mammals [8]. The advance organizer herein described was designed for nonmedical microbiology courses. Its goal is to encourage students to compare different types of metabolism and to emphasize their differences and similarities with respect mainly to energy metabolism. Given the fact that there are no identities but rather patterns and regularities to be verified, comparison is not trivial. This comparison is therefore placed at the level of analysis in the hierarchy of cognitive abilities, as established in Bloom *et al.*'s *Taxonomy of Educational Objectives* [9]. The use of high level questions as provided by the organizer herein described goes beyond the simple transfer of information and becomes a tool for the development of critical and analytical skills.

PROCEDURES

The advance organizer is particularly useful in courses based on collaborative learning¹ [10–12] and organized in small groups.² Such is the strategy we have been using in microbiology courses for biological sciences and biotechnology students. The advance organizer is made up of six diagrams (Fig. 1) representing the following types of bacterial metabolism:

- A. Anaerobic chemoorganotrophic (fermentation)
- B. Anaerobic chemoorganotrophic (anaerobic respiration)
- C. Aerobic chemoorganotrophic (aerobic respiration)
- D. Aerobic chemolithotrophic (aerobic respiration)
- E. Anoxygenic phototrophic (cyclic photophosphorylation)
- F. Oxygenic phototrophic (noncyclic photophosphorylation)

The organizer is presented together with the following problem, which must be resolved with the sole information contained in the diagrams.

Problem—Because of their great versatility, bacteria may obtain compounds essential to their survival and reproduction (ATP, NADPH, and a carbon source) in many different ways. Thus, they are able to live in a variety of different environments. Indicate what types of metabolism (A, B, C, D, E, and/or F) may be presented by bacteria living in environments I, II, III, IV, V, and VI as described in Table I by writing the corresponding letter(s) in the last column of the table.

For that purpose, analyze metabolic patterns found in

bacteria (A–F) and answer questions 1–4 for each of those patterns.

1. For synthesizing ATP from ADP + P_i,
 - a. Which of the compounds present in the environment are utilized?
 - b. What end products are released into the environment?
 - c. Is there use of an electron transport chain?
 - d. In instances where an electron transport chain is used, which compounds may be electron donors and which are final acceptors of electrons?
2. For obtaining NADPH,
 - a. What is the source of electrons?
 - b. Is there use of a proton gradient?
3. What is the primary carbon source for the biosynthesis of proteins, lipids, polysaccharides, and nucleic acids?
4. For which processes are ATP and NADPH used?

Full answers to all questions must be given using solely the six diagrams provided without access to any textbook. This procedure is essential to develop the intended skills and to avoid seeing the organizer as an illustration or a summary of each process. Rather, the organizer must be understood as basic information upon which it is possible to understand the various types of metabolism and to establish their general principles. Indeed, the analysis and comparison of the diagrams that make up the advance organizer allow the students to make accurate and definitive general observations before they review the detailed description of each type of metabolism. Following are the main observations.

1. Bacteria use chemical energy (Fig. 1, A, B, C, and D) or light energy (Fig. 1, E and F) to obtain ATP and NADPH.
2. Chemical energy may be obtained from organic (Fig. 1, A, B, and C) or inorganic (Fig. 1 D, E, and F) matter.
3. In all types of metabolism, the same coenzymes are present and are constantly recycled.
4. Several metabolic pathways are common to different types of metabolism, whereas others are present in specific groups only.
5. Electron transport chains may or may not exist. When present, they may vary as to the donor and final acceptor of electrons.
6. The direction of the electron flow may vary. In some cases, electrons flow toward the oxidized coenzyme (NADP⁺), in which case the proton gradient is dissipated.
7. Fermentation products may be released into the environment (Fig. 1A) or may become electron donors to an electron transport chain (Fig. 1B).
8. When bacteria have only one photosystem (Fig. 1E), light energy is used only in the synthesis of ATP and the oxidation of an inorganic substrate serves to reduce NADP⁺; when bacteria have two photosystems, light energy is used for both the synthesis of ATP and the reduction of NADP⁺ (Fig. 1F).

¹ Further information on cooperative learning can be obtained at www.co-operation.org (accessed February 17, 2005).

² A broad vision on small group teaching is provided, among other sites, by the Small group teaching index: www.brookes.ac.uk/services/ocsd/2_learnthch/small-group/sgtindex.html (accessed February 17, 2005).

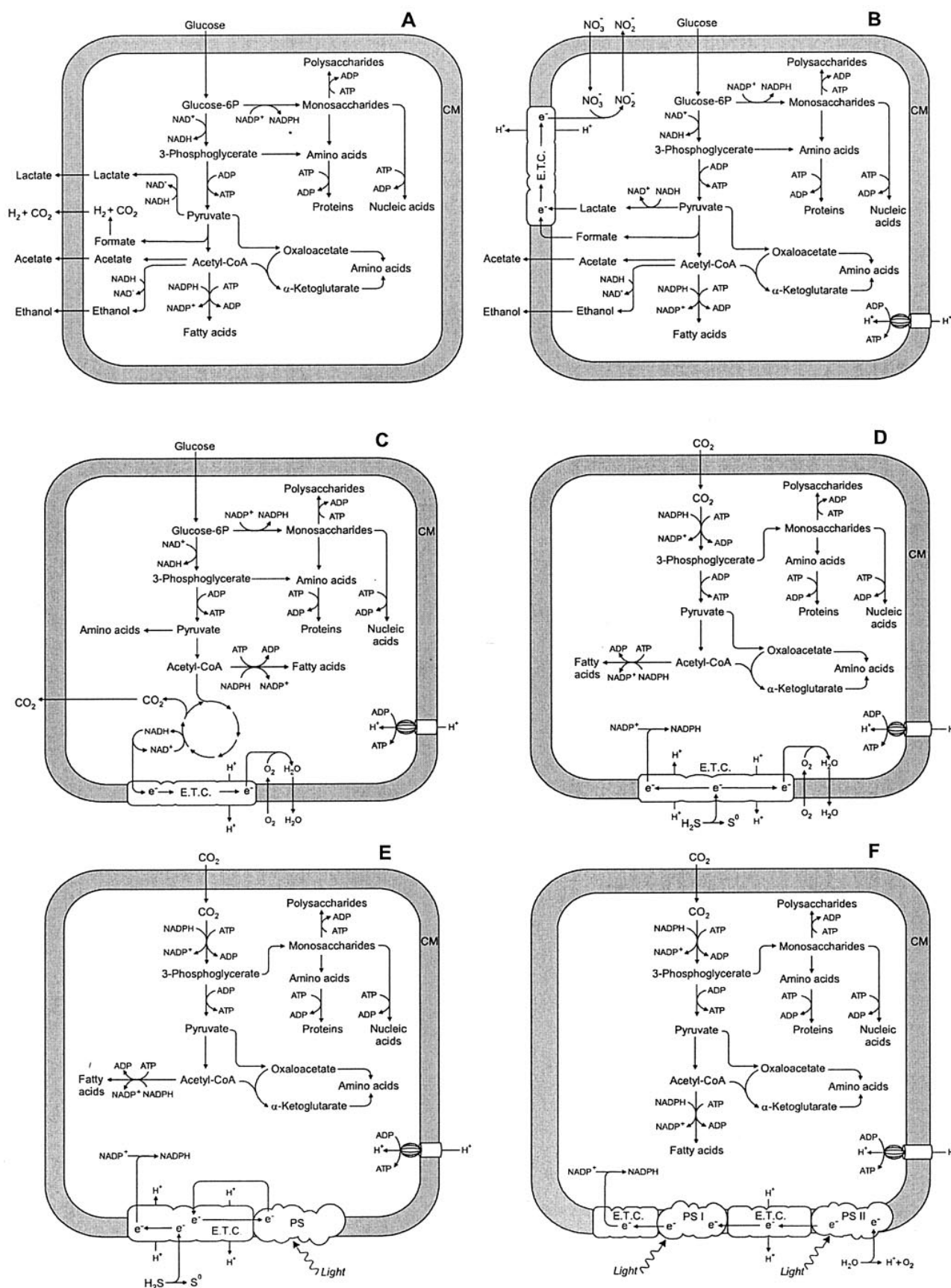


Fig. 1. **Types of bacterial metabolism.** The pathways are simplified; only key compounds are shown. CM, cell membrane; ETC, electron transport chain; PS, photosystem. Notice that the reactions are not stoichiometrically balanced.

TABLE I
 Characteristics of different niches occupied by bacteria

	Environment	Characteristics	Metabolic types ^a
I	Human intestine	Absence of light, anaerobic, high concentration of organic matter	
II	Human skin	Aerobic, high concentration of organic matter	
III	Sulfur mine	Absence of light, aerobic, high concentration of sulfur (S ⁰ and H ₂ S), low concentration of organic matter	
IV	Shallow lake water	Presence of light, aerobic, high concentration of inorganic matter, low concentration of organic matter	
V	Deep lake water	Presence of light, anaerobic, high concentration of inorganic matter, low concentration of organic matter	
VI	Deep soil	Absence of light, anaerobic, organic and inorganic matter available	

^a Correct answers are: I, A; II, C; III, D; IV, F; V, E; VI, B.

The adequate analysis of the organizer will allow the students to see the similarities and differences between metabolic types. It will also provide knowledge of the characteristics of the types of environment that favor the survival of each metabolic pattern. This understanding will enable the students to analyze and comprehend different and perhaps more complex metabolic processes than those represented in the diagrams. It must be underscored that, given the large diversity of bacteria, only a few types of metabolism were herein compared at the exclusion of (among others) the metabolic pathways of methanogen or heterotrophic, photosynthetic bacteria [13].

Further applications of the organizer offer the opportunity of other analyses, such as the integration between bacteria and their environment, or the changes brought about by bacteria growing in a particular niche. Indeed, major changes caused to the environment by bacteria [13] are due to either their unique ability to transform certain compounds (as chemolithotrophs do to iron ions) or to the rate of such transformation, or to both.

The organizer also allows for the study of the interaction among microorganisms, showing the students, for instance, that certain compounds produced by the growth of a particular type of bacterium may provide for the development of a whole community of organisms that would not be otherwise viable.

Faculty members and students who use this advance organizer argue that their experience has been most productive and that the organizer allows for the systematic and general understanding of metabolic processes. These same processes, when studied separately, are simply descriptive and difficult to understand.

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