The Fire of Life: Animal Energetics in the Secondary Classroom

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ABSTRACT

Teaching cellular respiration in the secondary classroom requires a carefully crafted approach. The discipline, though complex, represents the cornerstone of cellular metabolic transactions. Therefore, this article proposes a method to engage students in the subject through an agricultural lens. Specifically, this will be done by having students consider why animals eat feed and where feed energy goes. After developing an appreciation for such feeding dynamics in animals, students will be better suited for studying the molecular nature of cellular respiration.

Key Words: agriculture; animal energetics; biochemistry; cellular biology.

Introduction

In 1961, Max Kleiber published the first edition of The Fire of Life: An Introduction to Animal Energetics (Kleiber, 1975). At the time, this publication summarized centuries of previous work seeking to elucidate the complexities of the energy transactions (i.e., energetics) necessary for the maintenance of life. Specifically, this book discussed the developing notion that life can be considered as a form of controlled combustion, due to the “combustive” nature of nutrient oxidation. Indeed, over the years, this concept has continued to evolve to provide a novel understanding of the intricate energetic needs of organisms (Ferrell & Oltjen, 2008).

In the modern-day secondary classroom, educators generally teach about energetics through their cellular respiration units. Typically, these units elaborate on the concept that nutrients undergo oxidation through a series of synchronized metabolic reactions to yield adenosine triphosphate (ATP), a primary form of energy currency in physiological processes. In the context of eukaryotic cellular respiration, this nutrient oxidation is accompanied by the production of carbon dioxide and water; the former originates from the organic backbone of nutrients, while the latter originates from the reduction of oxygen gas on inner mitochondrial membranes.

We live in a time when global development requires us to be cognizant of sustainable solutions, rooted in scientific background, that adequately support our growing population. Therefore, if we educators are to teach students about the biological pathways through which nutrients act as fuel to promote our “fire of life,” we need to do so in a way that engages and promotes life-long learning skills in students (Tanner & Allen, 2004). This way, students can leave our classrooms with a better understanding of the molecular framework governing life and perhaps a spark of curiosity toward learning more about the dynamic nature of the subject contained therein.

Concepts in Animal Energetics

A textbook approach to teaching cellular respiration often begins with the successive plan of introducing glycolysis, continuing with the citric acid cycle, and concluding with the electron transport chain. Although there is nothing inherently wrong with this sequential approach to teaching energetics, deeper application and connection with the student audience is duly warranted (Harison, 2020). One way to provide an applied perspective on the importance of this discipline is through the inclusion of agricultural examples, as high school students have shown engagement in lessons linked to agriculture (Balschweid, 2002). Therefore, we propose the following approach to preparing students for a unit in aerobic cellular respiration.

Nutrient Energy Partitioning Model

A systematic method of studying energy transactions in animals can begin with a nutrient energy partitioning model (Figure 1). Such a model demonstrates, in succession, the partitioning of the energy contained in feed after it is consumed by an animal and represents an excellent visual tool to show students the energy transactions taking place after feeding. This model begins with considering the total potential energy (i.e., intake energy) consumed by an animal and represents it as a primary form of energy currency in physiological processes. In the context of eukaryotic cellular respiration, this nutrient oxidation is accompanied by the production of carbon dioxide and water; the former originates from the organic backbone of nutrients, while the latter originates from the reduction of oxygen gas on inner mitochondrial membranes.
with other endogenously derived energy; i.e., cells sloughed off from the gastrointestinal lining or microbial cells caught in the passage of digesta). Digestible energy, then, represents the energy that does not get excreted as fecal energy. However, some of this digestible energy is prone to being lost through processes such as the production of gases (i.e., due to microbial action) or through passed urinary energy. Metabolizable energy is the energy from feed that is actually available for metabolic transactions inside of an animal. If this energy is captured and retained by an organism in the form of tissue, eggs, milk, wool, or a conceptus, this can be called recovered energy. However, we need to understand that the physiological events taking place with each of these aforementioned transactions have the potential to release energy in the form of heat. One example of such a process is peristalsis, the contractions that push ingesta along the gastrointestinal tract. These smooth muscle contractions rely on the energy provided by ATP; hydrolysis of ATP is an exothermic reaction. The author was not able to find an example in literature that suggests the use of this type of a nutrient energy partitioning model to prepare secondary-level students to understand the need for cellular respiration in higher-order eukaryotes.

**Nutrient Requirements of Animals**

The National Academies of Sciences, Engineering, and Medicine publish periodic manuals, colloquially called “NRC books,” that provide up-to-date information on the nutrient requirements of various animals (National Research Council, 2021). These manuals provide a foundational understanding of the energy and nutrient requirements of various species, at different stages in a life cycle. Contained within these manuals are also feed composition data, representative of the feeds typically fed to the animal emphasized by the manual. These feed composition tables depict the nutrient analysis of feeds, including the potential energetic value of the feeds in question. While these manuals provide the hallmark values commonly accepted as valid for animal requirements and feed properties, these values, in addition to newly proposed parameters, can easily be obtained by instructors and students through web searches of literature, including extension outreach communications.

**Sample Lesson**

The following example is a five-day lesson that prepares students for a unit on cellular respiration.

- **Day 1**
  - Discuss feeding diversity/behavior of domesticated animals (watch videos depicting these processes or take class on a field trip to visit animals).
  - Use NRC manuals on animal nutrient requirements or online literature to showcase energetic requirements of various animals and the chemical composition of common feeds.
  - Students begin a weeklong food log to record their personal diet.

- **Day 2**
  - Introduce students to basic mathematical applications in formulating dietary rations of animals to meet their energetic needs.
  - Example: A 680 kg lactating dairy cow produces around 25 kg of milk per day. As a result, she requires a daily diet that provides 28 megacalories. How much of a mixed diet should be fed to this cow if each kilogram of the mixed diet contains 1.3 megacalories? Feed-composition data and up-to-date feed prices to be used for these ration formulations can be found on agricultural extension websites for major land-grant universities (Hall et al., 2009; PennState Extension, 2020).
  - Have students design similar problems in groups. Tell students that they will use these problems to make a group assessment that they will administer to the students the following day.

- **Day 3**
  - Formative group assessment using student-designed diet formulation problems.
  - Touch base on personal diet logs and discuss as a class.
  - Remind students to keep up with log entries and discuss, as a class, the size and frequency of meals.
  - Students are taught how to search the internet to identify the caloric content of the various foods they are consuming.

- **Day 4**
  - Introduce students to the nutrient energy partitioning model (Figure 1).
  - Students use computer programs such as Google Slides or PowerPoint to develop a nutrient-partitioning model

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**Figure 1.** Nutrient energy partitioning model (modified from Ferrell & Oltjen, 2008). Solid lines reflect energy that is consecutively retained for further processes. Dashed lines reflect energy losses into nonrecoverable forms. Notes: 

- **a** Thermal energy resulting from gastrointestinal physiology, basal metabolism, thermal regulation, product formation, voluntary activity.
- **b** Potential energy recovered in tissue, milk, eggs, conceptus, hair, wool, feathers.
for a selected animal that they will be assigned after blindly drawing its name from a hat.

• **Day 5**
  • Students present their nutrient energy partitioning models and discuss the dynamics of their example. For instance, where would their selected animal’s nutrients normally be partitioned? (examples: heat energy due to constant movement, recovered energy due to conceptus, recovered energy due to growth, etc.). Emphasis must be placed on energy losses that occur post-consumption, and on how these losses can impact the management of animals (economically and biologically) and the surrounding environment.
  • Students finish their presentation by connecting back to their weekly food log and reflecting on their personal dietary choices; they discuss their dietary habits, including the origins of the foods consumed, frequency of eating, and the caloric content of their diets.

### Moving Forward

Given the vibrant momentum of global development, dependence on agricultural successes has continually been an obligation for our growing population (Tilman et al., 2001). Therefore, we, as educators, should be focused on developing new ways to engage students in science, through agriculture. Having completed an introduction to basic animal energetics, students can use this established knowledge to successively approach cellular respiration with a deductive approach. In other words, by focusing on the “big picture” of why organisms eat, students can be guided through the organizational hierarchy of how food serves as cellular fuel. This way, students will be able to understand why cellular respiration is relevant and why it can be considered the fire that supports our lives.

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