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Establishing Students' Abilities to Reason with Relationships in the Context of Cellular Respiration

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Introduction

Recent studies show that adults today lack the critical problem solving skills and knowledge needed for the science, technology, mathematics, and engineering fields[1]. In response, educators, especially those in the life sciences, are being urged to equip students with the skills associated with the scientific inquiry process, which includes a systems thinking approach[2].

The ability to comprehend simple relationships between or among the system’s components is one of eight characteristic abilities in the System Thinking Hierarchical Model (STH) Model[3]. Therefore, it is expected that reasoning with simple relationships is an ability that should be mastered by introductory biological science students.

Glycolysis → results in → Pyruvate

Figure 1. An example of a simple relationship students should have mastered.

Cellular respiration can be considered a model topic covered in most introductory level classes. This study aims to establish the level at which University of Nebraska-Lincoln students reason with simple relationships in the context of cellular respiration at the levels of glycolysis, Krebs cycle, and electron transport chain. Students are generally taught these 3 processes in order and may have received different levels of emphasis on the processes. These processes are component processes of cellular respiration and each has multiple inputs and outputs. Cellular Respiration contributes to how all living organisms convert food sources such as glucose into usable energy and is a necessary foundation to other biological topics such as biochemistry, therefore it is critical for students to understand how it works to truly know biology.

Research Question

How do students reason with the three main processes of cellular respiration?

Method

Conceptual Models

During their LIFE 120 laboratory sections, all students were instructed to represent their understanding of cellular respiration through the creation of a conceptual model (Fig 1). Students were given a list of 20 relevant terms. Students were permitted to add components not listed in the component bank.

Data Processing

633 student consented to this research (IRB #14466). 18 student models were randomly selected and digitized using CmapTools and processed as text propositions in excel. Classroom observations were used to determine structures and relationships that were inputs and outputs to the 3 processes. An example can be seen in (Fig 2) with O_2 as an output of the electron transport chain. The inputs and outputs for each process were scored with a correctness rubric.

Correctness

The correctness rubric used had a scale from 1-3. The score from the scale represented relationships that were:

1 – Incorrect
2 – Plausible but too vague
3 – Scientifically accurate

Results

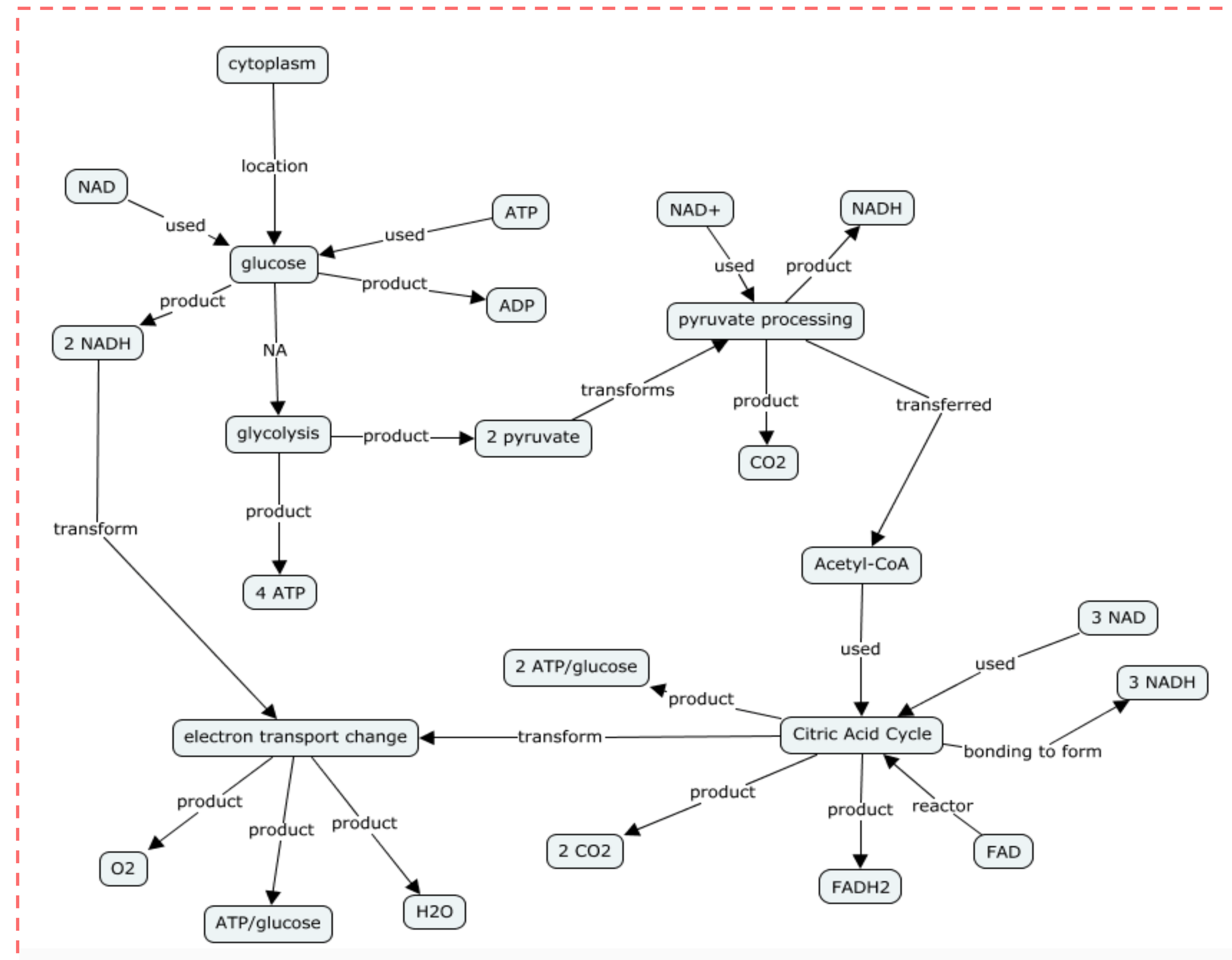

Figure 2. Example of student made conceptual model

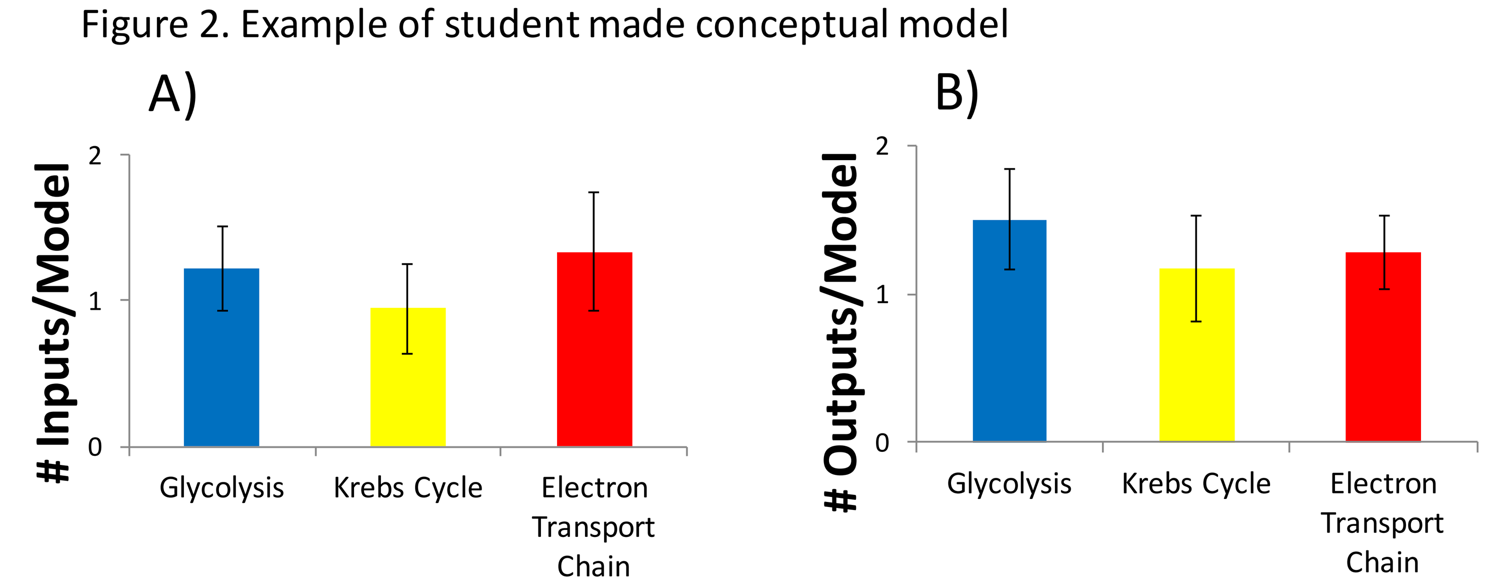

Figure 3. The mean number of inputs (A) and outputs (B) included in models

- Students did not include different numbers of input or outputs ($p > 0.05$) when describing glycolysis, Krebs cycle and the electron transport
- Students had about 1 input and more than 1 output per process

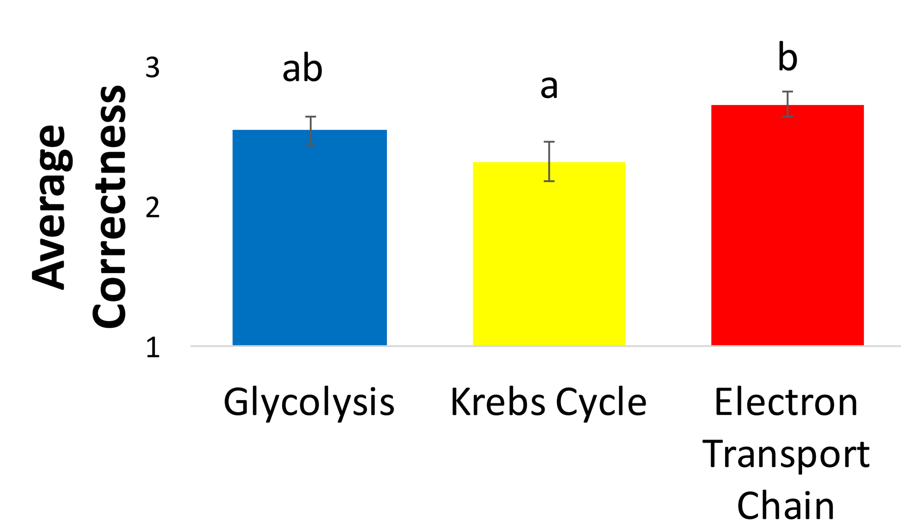

Figure 4. Average correctness of relationships connected to Glycolysis, Krebs cycle and, ETC

- Relationships associated with Krebs cycle were significantly lower quality (2.3) than relationships associated with ETC (2.7, $p < 0.04$)
- Relationships associated with glycolysis were intermediate in quality (2.5)

Results

Inputs			Outputs		
Glycolysis	Krebs Cycle	Electron Transport Chain	Glycolysis	Krebs Cycle	Electron Transport Chain
ADP	Acetyl CoA	Electrons	ATP	NADH	ATP
ATP		NADH	Pyruvate	$FADH_2$	Water
Glucose		$FADH_2$	NADH	ATP	FAD^+
				CO_2	NAD^+

Table 1. Inputs and outputs that were included by >2 students

- Students included 3-4 different outputs for each process of cellular respiration
- Students included 3 inputs for glycolysis and electron transport chain and 1 for Krebs cycle
- The common inputs and output are accurate, but there are missing components (e.g, FAD+ as input for Krebs cycle).
- 61% of students did not include an input or output to glycolysis

Conclusions & Discussion

Although students included only 1 input and output for each process (Fig 3), there are more that exist for each process (Table 1). From the component bank, students should have had between 3-4 inputs and outputs for each process. Still, out of the relationships students included in their conceptual models, they are fairly accurate with the ones related to the electron transport chain being more accurate than the Krebs cycle, and relationships associated with glycolysis intermediate to the other two processes.

All three main processes are essential to the understanding of cellular respiration as a whole. If students are not reasoning with all of the smaller components at a high level, then they need to develop their skills before they can consider the system holistically. A different approach that improves student’s system thinking skills should be considered. For example, computational modeling is one approach that has been recently investigated[4]. It can help students better understand the components, relationships, and processes of biological systems like cellular respiration.

Acknowledgments

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