

How Students Use Mass Balance Reasoning to Understand Biological Phenomena

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Overview: We investigated how students use mass balance reasoning to gain a deeper understanding of how matter moves through biological systems. Our aim was to lay the groundwork for a mass balance learning progression in physiology.

Audience: Post-secondary Educators; Secondary Educators; Science Education Researchers

Key Points

- Mass balance reasoning is a powerful conceptual scaffold that students can use to explain diverse biological phenomena that involve matter flows (i.e., matter fluxes).
- To use mass balance reasoning productively, students must combine their scientific content knowledge about matter flows in biological systems with mathematical thinking involving covariational reasoning.
- Instructors can help students develop rigorous mass balance reasoning by drawing their attention to how matter flows into, and out of, key biological compartments (e.g., cell) and helping them determine net flow rates.
- By understanding how to use mass balance reasoning, students gain a powerful reasoning strategy that can help them understand numerous phenomena and build intellectual coherence across scientific fields.

INTRODUCTION In recent years, there has been a strong push to transform STEM education to help students learn to think like scientists. This transformation involves redesigning instruction and curricula around fundamental scientific ideas that serve as conceptual scaffolds students can use. In this study, we conducted interviews with post-secondary students to investigate how students use mass balance reasoning as a conceptual scaffold to gain a deeper understanding of matter movement in biological phenomena (e.g., cellular respiration, photosynthesis). Our aim was to lay the groundwork for a mass balance learning progression in physiology.

FINDINGS We identified two progress variables in a preliminary learning progression framework that described how student performances developed as students become more fluent with mass balance reasoning. The first progress variable described how students identify and use matter flows to explain biological phenomena. Students who expressed informal ideas focused on how matter flows into—but not out—biological compartments (e.g., a cell), while students with more formal ideas described multiple, simultaneous matter flows into and out of compartments. The second progress variable described how students use covariational reasoning from mathematics to explain how matter accumulates or decreases in a compartment. Students who expressed informal ideas focused on the direction or magnitude of single matter flows while students with more

formal ideas integrated multiple matter flows to determine a net rate-of-change. We suggest instructors can help students develop rigorous mass balance reasoning by using instructional strategies that draw students' attention to the multiple matter flows in a phenomenon and guide them through integrating those matter flows into net rates of change when explaining biological phenomena.

TAKEAWAYS Our work provides one example of how students can engage in three-dimensional learning, which is a primary goal of science education. It does this by showing how student performances associated with the practice of mathematical thinking (i.e., covariational reasoning) reveal students' understanding of the core concept of matter flows (through mass balance reasoning) as governed by the crosscutting concept of matter conservation. Instructors can use our preliminary mass balance learning progression to inform their instructional approaches so they support students through some of the more challenging aspects of mass balance reasoning, namely accounting for, and integrating, all relevant matter flows to explain biological phenomena. By understanding how to use mass balance reasoning, students gain a powerful reasoning strategy that can help them understand numerous phenomena and build intellectual coherence across scientific fields.

How Students Reason about Matter Flows and Accumulations in Complex Biological Phenomena: An Emerging Learning Progression for Mass Balance