

How do biology undergraduates “explain” photosynthesis? Investigating student responses to different constructed response question stems

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Automated Analysis of Constructed Response (AACR) research group



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Overview


- Using constructed response questions: benefits and challenges
- Research question: Altering a photosynthesis question stem
- Using computerized tools to analyze written responses
- Results
- Discussion



Using Constructed Response Questions

- Multiple choice questions require students to separate and favor presented choices (Birenbaum & Tatsouka 1987)
- Constructed response questions require students to create a written answer from their rationalization of the question and the concepts involved in it (Kuechler & Simkin 2010)

Kuechler, W.L., & Simkin, M.G. (2010). Why is performance on multiple-choice tests and constructed-response tests not more closely related? Theory and an empirical test. *Decision Sciences Journal of Innovative Education* 8: 55–73.

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- Expert vs. novice reasoning
 - A challenge to using constructed response questions is writing the stem so that it is meaningful to students

Ambiguity in Responses

Stem Version One (Fall 2009):

A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram.

Explain this huge increase in biomass.

The increase is due to a large absorption of minerals and organic materials through the soil then joining their benefits with H₂O, O₂ and sunlight to help reach maximum production.

The maple tree is able to increase the mass so much because a majority of the mass is due to CO₂ gas from the atmosphere. The green leaves on the tree absorb the CO₂ and increase the maple tree's mass.



Research Question

- Answering this question requires naming a process
- What is the impact on students' written explanations when they are explicitly asked to identify a process in their response?

Methods

Stem Version One (V1) (Fall 2009):

A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram.

Explain this huge increase in biomass.

Stem Version Two (V2) (Fall 2010 & Fall 2011):

A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram.

Explain where this biomass comes from and by what process.

Study Design

- Cells and Molecules
 - Introductory biology course
 - Prerequisite is general chemistry
- Post-instruction on photosynthesis
- Given on an exam

V1: A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. **Explain this huge increase in biomass.**

Fall 2009: 385 students

V2: A mature maple tree can have a mass of 1 ton or more (dry biomass, after removing the water), yet it starts from a seed that weighs less than 1 gram. **Explain where this biomass comes from and by what process.**

Fall 2010: 394 students

Fall 2011: 458 students

Categories

Statistics

Build Extend

All Records (1,232)

Uncategorized (45)

Photosynthesis (849)

Carbon Dioxide (590)

Water (585)

Glucose/Sugar (534)

Substance (526)

Solar Radiation (520)

Roots/Soil (414)

Process (406)

Energy (395)

ATP (299)

Respiration (273)

cellular respiration (193)

respiration (58)

krebs cycle (19)

krebs cycle cycle (17)

glycolysis (17)

oxidative phosphorylation (7)

Cell Division (191)

Oxygen (183)

Atmosphere (148)

Carbon (127)

Electron Transport Chain (111)

Mitochondria (32)

plant (412)

process (406)

energy (387)

seed (357)

solar energy (348)

nutrients (347)

ato (298)

sugar (294)

glucose (271)

soil (267)

tree (253)

cell (232)

calvin cycle (227)

also (213)


not more (213)

Categories

Terms

Responses with
terms
highlightedResponse
Categorization

Id	Response	Categories
3C98556E18EBF6B 6BADE6167CC47A6 D77B54C6D5	Using photo- up water to grow a	Carbon Dioxide Photosynthesis Respiration Substance Water
9E8B79226B200373 FA8D35EC0D138D9 8FE54CD11	The water and CO ₂ in the environment are combined to form glucose which is stored in the cells.	Carbon Dioxide Glucose/Sug Water
0E5DD742AB87097 9EF9E0DB09185E7A B7E53900B	Biomass came from photosynthesis and the absorption of organic materials. Through photosynthesis and cellular respiration the plant grew to its new mass.	Photosynthe Respiration Substance
65E7717BDBC4554 A91DF9E338940331 7D9C5D6A4	The biomass came from the light reaction in photosynthesis, H ₂ O splitting to release O ₂ → photosystem II and Photo I going into the calvin cycle to make glucose using the ATP and CO ₂ . This energy is then used to help the plant grow and excess energy is stored in the roots. Summary: seed → sapling → infant corn → mature C4 H ₂ O + light + CO ₂ mature corn.	Photosynthe ATP Carbon Dioxide Energy Glucose/Sugar Roots/Soil Solar Radiation Water
4676ADD0AD0CB92 3464CAA27AA9D2EB EC758575C	The biomass comes from all the CO ₂ that the corn takes in. Also, the minerals and water taken in by the roots. With all these things and photosynthesis the corn grows producing all the biomass.	Carbon Dioxide Photosynthesis Roots/Soil Substance Water
41E1861A0954AA7B 68268FD1566D9295 AAADC8B7E	The massive increase in biomass can be attributed to the dry seed taking in nutrients and growing and forming into a plant that utilizes the solar energy, for photosynthesis in chloroplasts in light rxns. As the cell takes in energy, they build and keep growing more cells, that add structures and biomass. Also, dark rxns couples with light rxns produce energy and the more energy it has and keeps maintaining. The more it can grow and prosper. Water is absorbed and gets oxygen from ETC to produce more and more ATP for growth. Photosynthesis accounts for glucose increase that give off ATP when broken down.	Solar Radiation ATP Carbon Energy Glucose/Sugar Oxygen Photosynthesis Substance Water
164C3B45905D947 716F0C63A3CB0BD 4093C137CB	From CO ₂ of H ₂ O being added through photosynthesis.	Carbon Dioxide Photosynthesis Water
495961FC4520CCD 412E449AA1973A16 3522226F5	This increase in biomass comes from the CO ₂ the plants intook during photosynthesis. With the CO ₂ it intook it fixed the carbon, making glucose as a by product, further increasing it's net energy, allowing the plant to grow more.	Carbon Dioxide Carbon Energy Glucose/Sugar
EE31C9A7E7B4616 042AC850D23F9DA3 C35801F61	The 5-10kg of seeds slowly go through cellular respiration at first from sugars enclosed in the capsule. Seeds eventually grow and obtain leaves where photosynthesis occurs and the Calvin Cycle, CO ₂ from the atmosphere is fixed into G3P	Glucose/Sugar Photosynthesis Carbon Carbon Dioxide

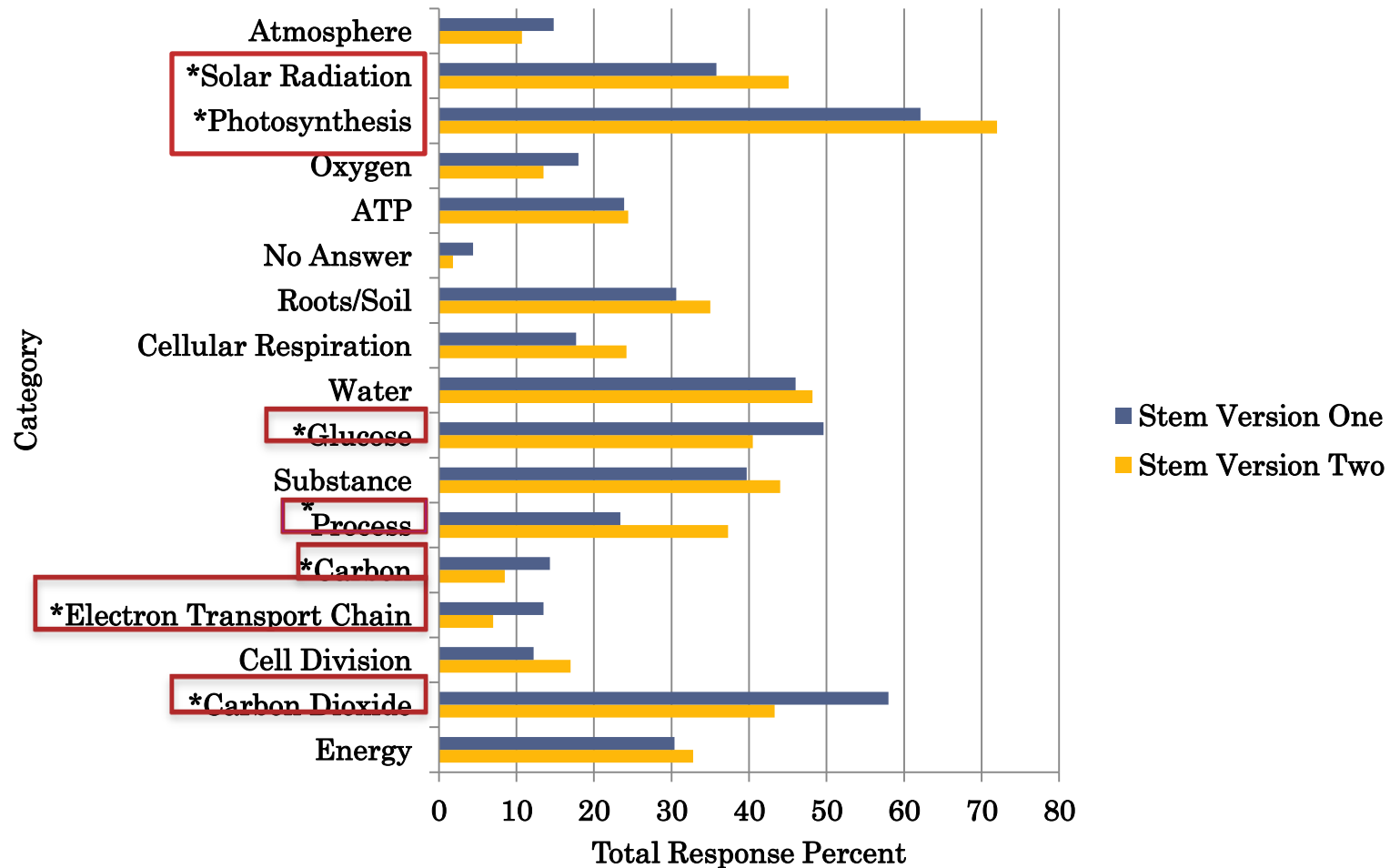
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- Each response can be put into multiple categories depending on the content of the answer
 - The following response was put into three categories: *substance*, *energy*, and *glucose*

*As the tree grows it makes **organic materials** such as **glucose**. As these **organic molecules** build up some are used to make **energy** while others are stored up, causing the tree to grow. The tree forms more and more cells which increases the weight of the tree.*

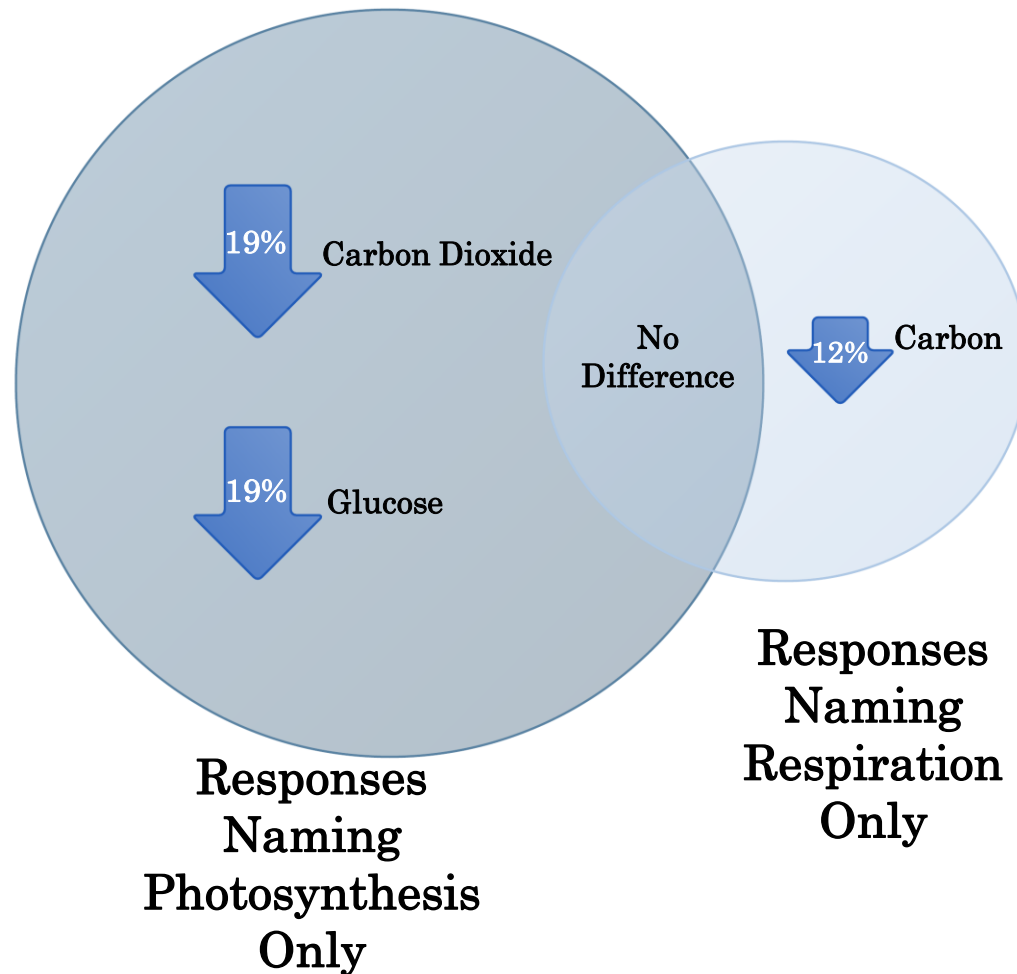
Statistical Analysis

- Our lexical analysis included sixteen categories to classify the responses
- Independent two-sample t-test on each category

Distribution of Categories



Difference in Biomass Inputs & Outputs Between V1 and V2



Example Responses

- Stem Version One

*The maple tree absorbed lots of **H₂O** (sic) over the years and used that to make ATP and glucose. Both of these products were used to grow this tree and some **glucose** may have been stored away. So even though the **H₂O** (sic) was removed, it still is able to keep its size due to its large storage amounts of **nutrients**, glucose and water.*

*The huge increase in biomass from the seed has weight less than 1 gram is due to all of the **organic molecules** it takes in during the tree's lifetime, the tree takes in **CO₂** from the air and takes in **H₂O** from the ground with its roots. More of that is contained inside the maple tree so that it can use it to do work.*

Purple Font = Processes

Red Font = Biomass Input or Output

- Stem Version Two

*Process responsible for increased biomass is **photosynthesis**. The biomass came from the incorporation of **CO₂ gas** from the atmosphere that was delivered to molecules in the green leaves, **sunlight** helps create **glucose** and **nutrients** moved to roots.*

*This biomass came from the processes of **photosynthesis** and the **calvin cycle** that occur within the leaves of these plants. In **photosynthesis** the plant takes in **sunlight** and uses this energy to produce ATP and NADPH for the **calvin cycle**. Then, in the **calvin cycle** the plant uses the ATP and NADPH, and combines it with **CO₂** from the air to produce **sugar** or **starch**. This **starch** accumulates in the plant leaving the plant weighing more than it was initially.*

Purple Font = Processes

Red Font = Biomass Input or Output

Discussion

Correct Processes

Photosynthesis
Electron Transport
Chain

Incorrect Processes

Solar Radiation
Cell Division
Respiration

Red = Significant Difference
between V1 and V2



Inputs and Outputs

*The huge increase in biomass is due to the absorption of **organic substances** from the soil (mainly roots) – **photosynthesis***

*It gets all of its mass from going through **photosynthesis** and generating all the extra biomass.*

Purple Font = Processes

Red Font = Biomass Input or Output



Conclusion

- Even small changes in wording can influence how students respond.
- If the question is written so that it is clear to novices the amount of scientific detail they should provide in their answer, then they will provide more meaningful responses.



Future Work

- Why were inputs and outputs lost?
 - Split design –change order of “where biomass comes from” and “by what process”
- Examine ambiguity in other content areas
- Rubric scoring
- Refine categories
 - How are students using sunlight?

Questions

- The paper can be found on the conference CD
- Correspondence should be sent to Michele Weston. Contact:
westonmi@msu.edu
- <http://aacr.crcstl.msu.edu>