

# Covariational Reasoning and Item Context affect student language in undergraduate Mass Balance explanations.

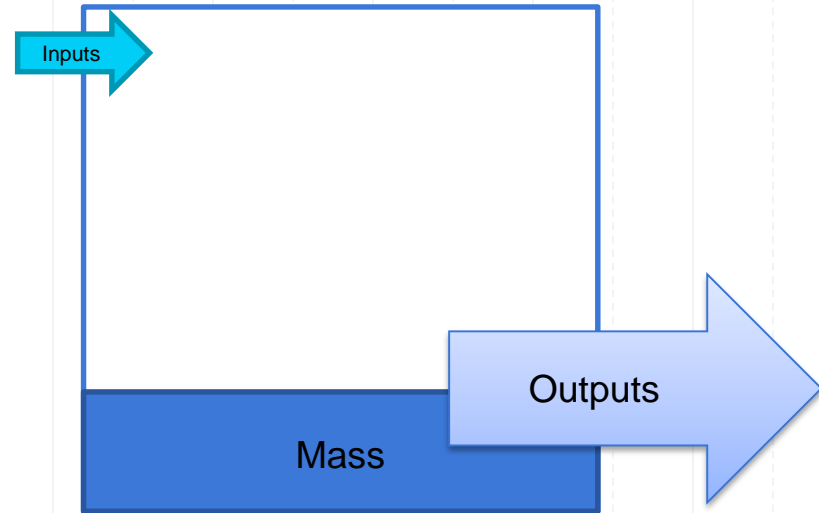
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SABER 2022



# Mass Balance (MB) Reasoning

## Pool and Flux / Accumulation

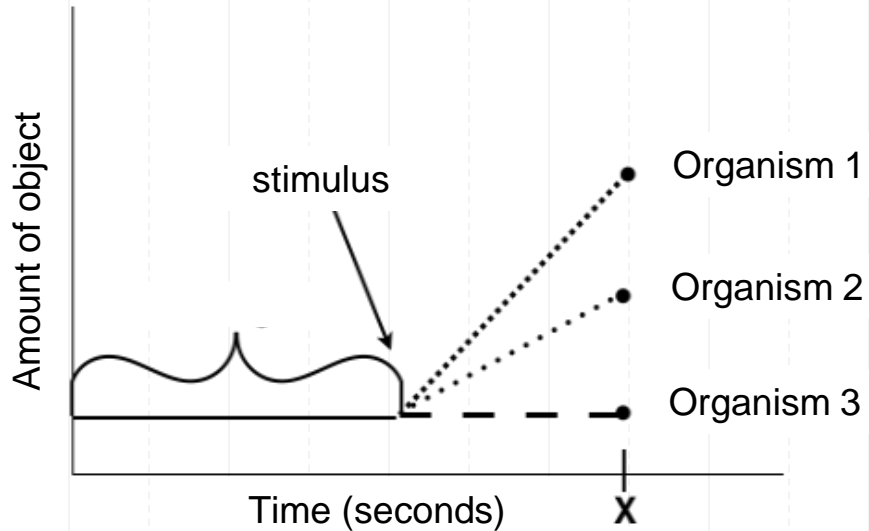
- Broadly applicable across science disciplines.
  - Identify fluxes
  - Apply Covariational Reasoning (CVR)
- Difficulty persists even for graduate students. (Sweeney & Sterman, 2007)
- Little work examines the language students use in MB explanations.



# Provoking MB explanations

- Constructed Response allows students to use their own words to construct an explanation.
  - Measures knowledge-in-use. (Krajick, 2021)
  - Reveals student thinking
- Students are sensitive to item context. (Nehm & Ridgeway, 2011; Nehm & Ha, 2011)
- Constructed Response prompts successfully assess Mass Balance reasoning. (Scott et al, 2022)
  - Aligns to a learning progression.
  - Across six contexts.
  - Reflective of interviews.

# Provoking MB explanations



**Oak:** In the leaves of an oak tree, photosynthesis makes glucose while cellular respiration breaks down glucose.

- Explain how *organism 1* has more *object* compared to *organism 2* and *3* given that all *organisms* have the same rate of *input*.
- Explain how *organism 3* has no change in *object* while *organism 1* and *2* both show increased *object* given that all three have the same rate of *input*.

# Research Questions

1. What language is used to demonstrate skills in covariational reasoning (CVR)?
2. What are the effects of context?

1,920 CRs

Six Contexts

- Oak
- Rat
- Rower (human)
- Cat
- Hawk
- Pea

Four CVR levels

- Lowest (CVR1) → Highest (CVR4)

# Methods

## Thematic Coding

- Holistic
- Learning Progression
- Low (CVR1) to high (CVR4)

Scott et al. 2022



## Language Diversity

- Adapted from ecology
- Bray-Curtis Dissimilarity
- Ordination

Shiroda et al., *in review*



## Text-based Content Analysis

- Predictive words associated with a CVR level
- Based on word frequency

# Ecological Diversity and Language

- Quantitative metric of diversity.
- Each site is a response
- Each species is a word.
- Bray-Curtis Dissimilarity compares the words in each response.
  - Scale of 0-100
  - Low numbers → low diversity → responses are MORE similar
  - Categorical data overlaid

Ecological	Species 1	Species 2	...	Species n
Site 1	3	0	...	1
Site 2	1	4	...	2
...	...	...	...	...
Site $n$	0	1	...	0

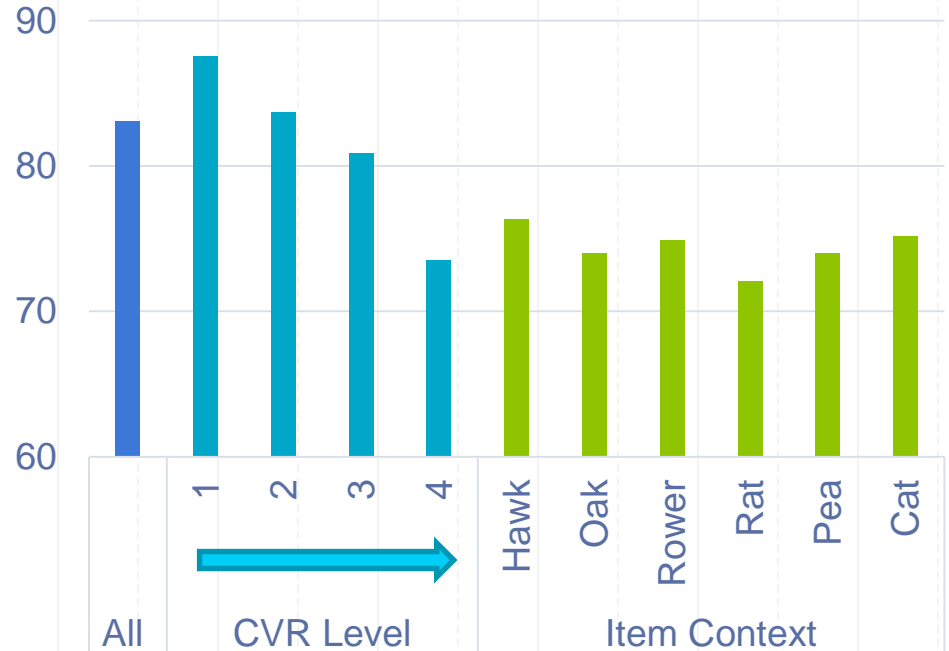
Lexical	Word 1	Word 2	...	Word $n$
Response 1	3	0	...	1
Response 2	1	4	...	2
...	...	...	...	...
Response $n$	0	1	...	0



# Ecological Diversity

## Bray Curtis Dissimilarity

- Overall = 83 (17% shared)
- Similar across Context, but lower within groups than overall data set
  - More similar within context.
- Decreases as CVR increases.
  - CVR4 CRs are more similar to themselves in spite of context.

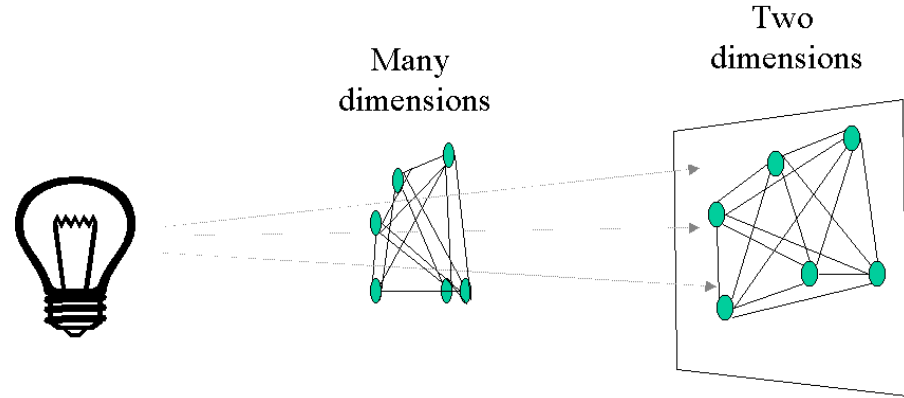




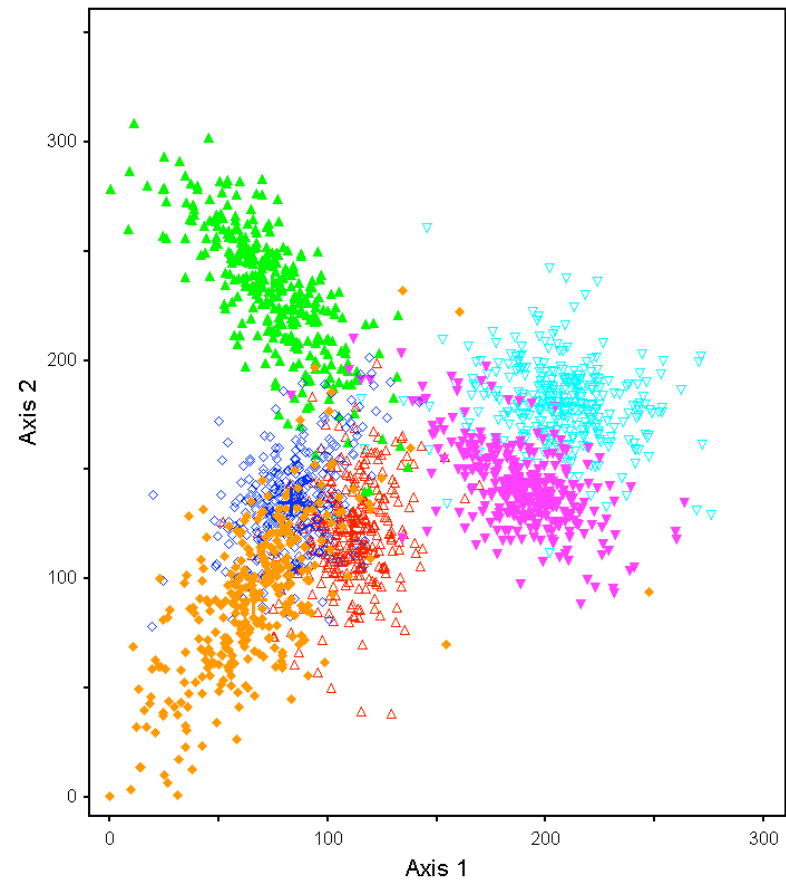
# Ecological Diversity

## Ordination

- Dimension reduction technique
- Visualization of similarity between responses based on words.
- Responses that are closer together share more words.
- Overlay categorical data

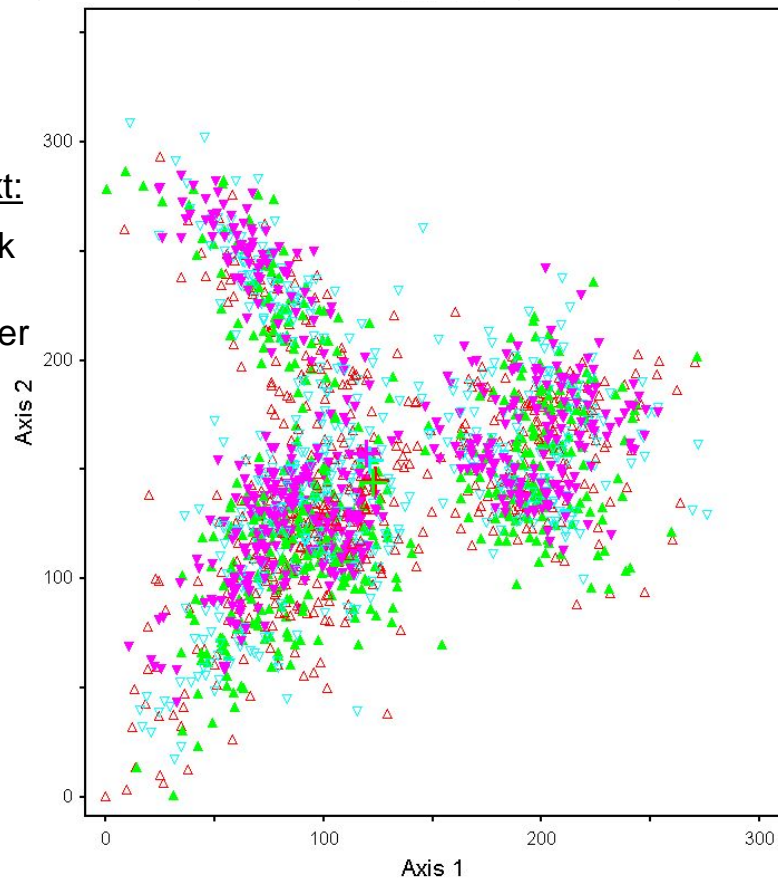


<http://ordination.okstate.edu/overview.htm>



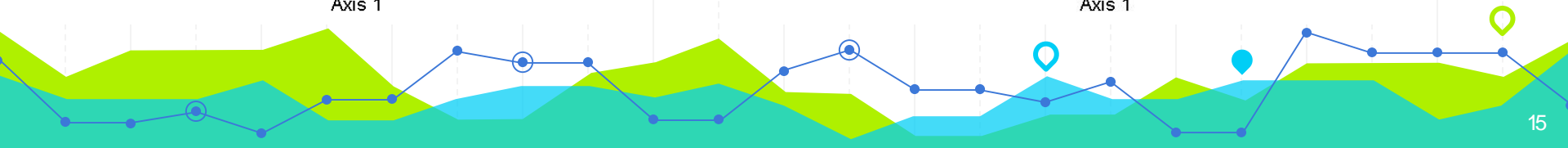
Context:

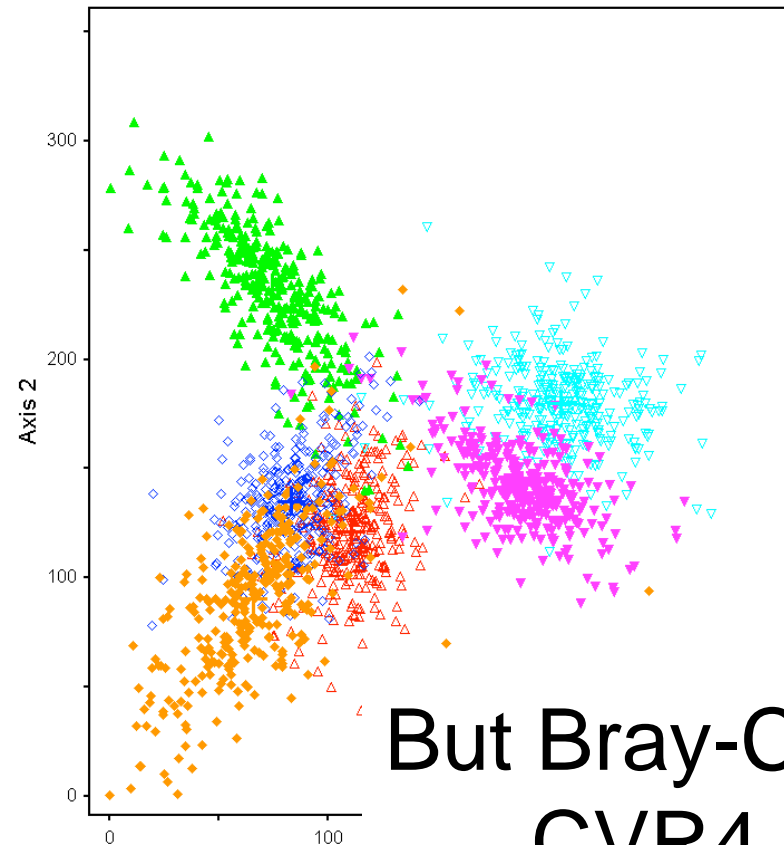
- △ Hawk
- ▲ Pea
- ▽ Rower
- ◆ Oak
- ◆ Cat



CVR Level:

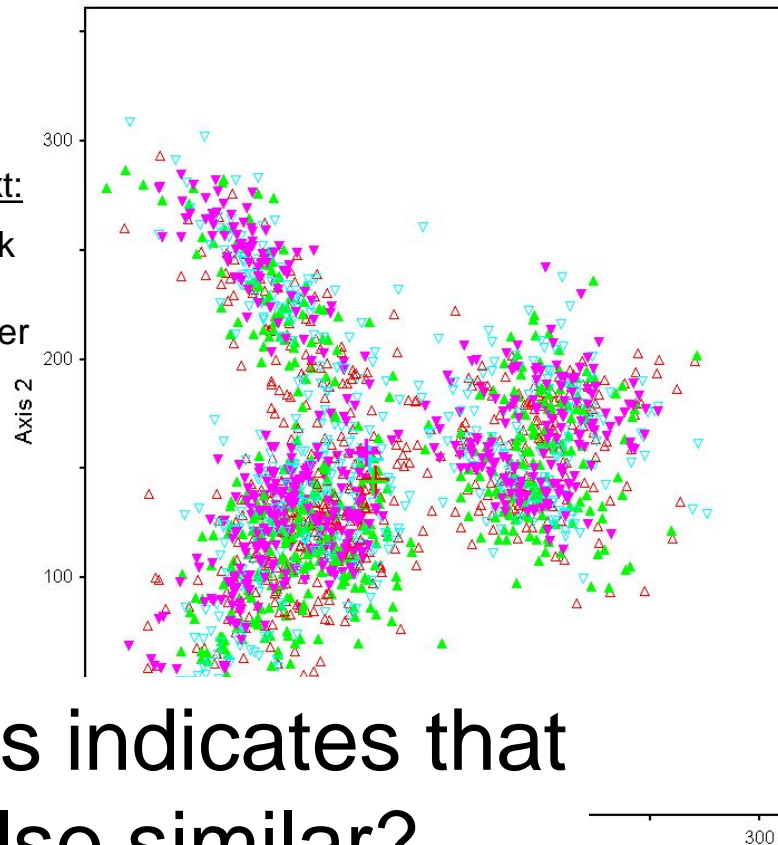
- △ 1
- ▲ 2
- ▽ 3
- ▽ 4





Context:

- △ Hawk
- ▲ Pea
- ▽ Rower
- ▼ Rat
- ◇ Oak
- ◆ Cat

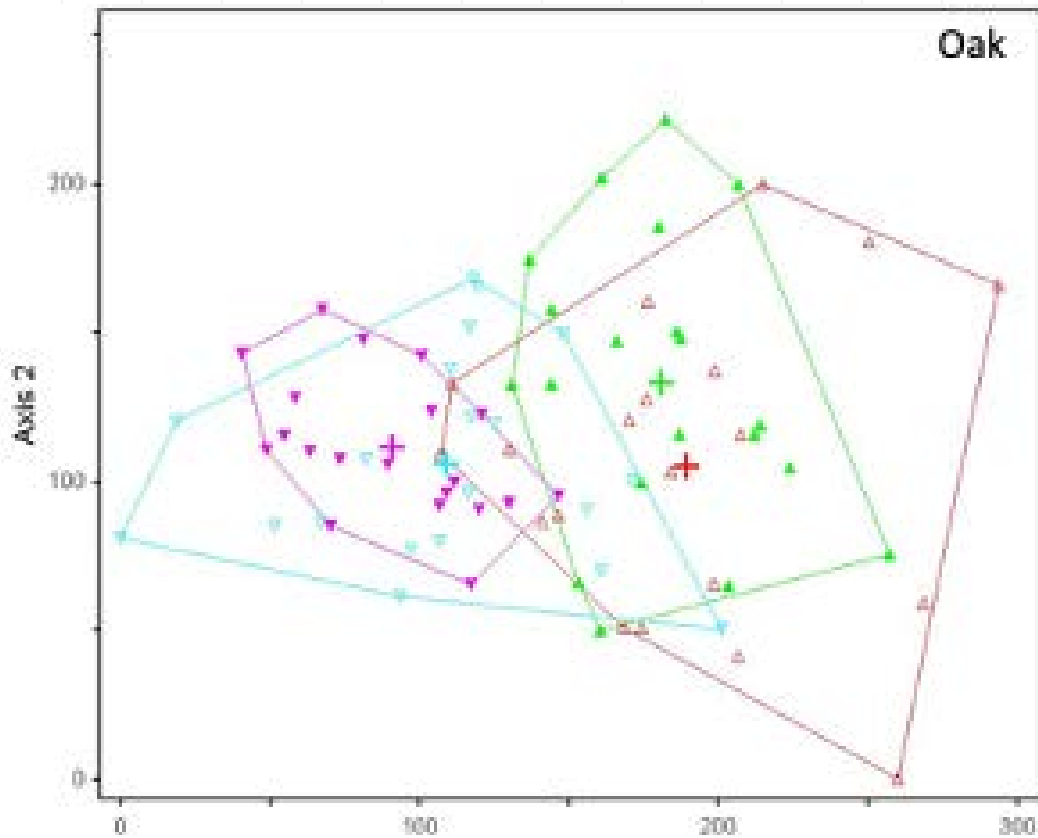


CVR Level:

- △ 1
- ▲ 2
- ▽ 3
- ▼ 4

But Bray-Curtis indicates that CVR4 is also similar?





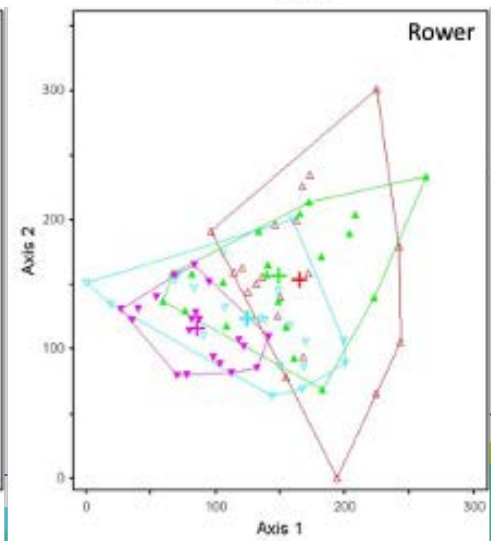
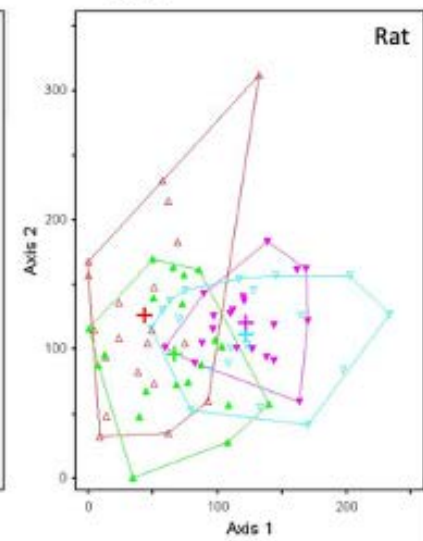
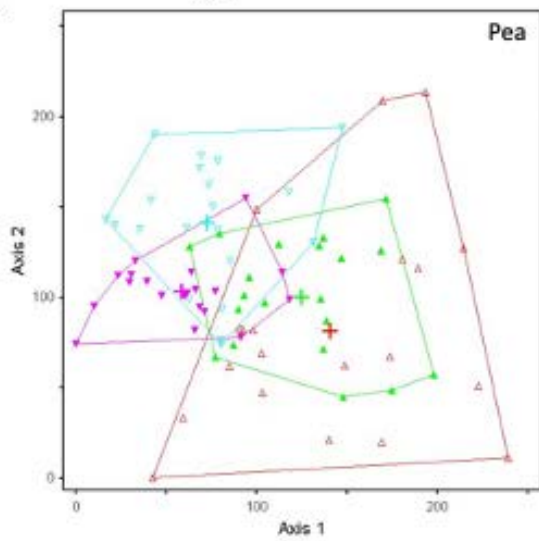
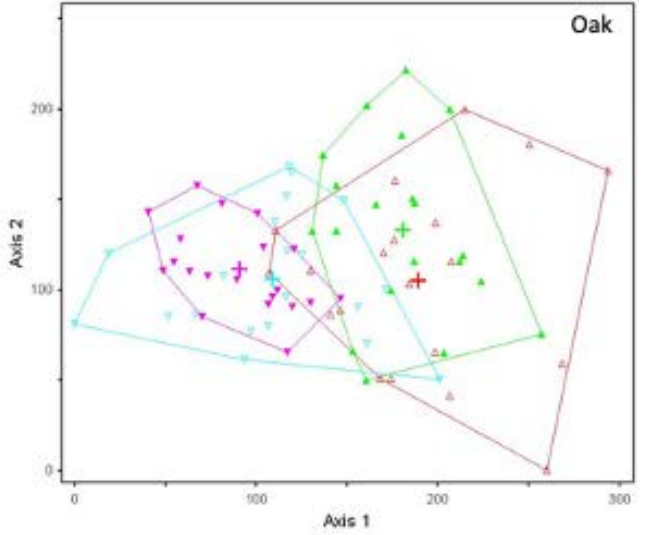
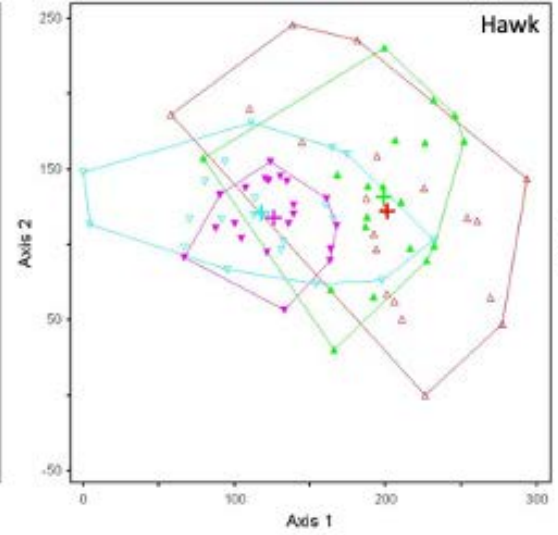
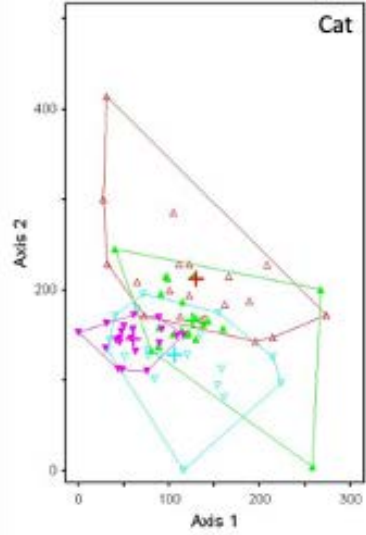
CVR Level:

- △ 1
- ▲ 2
- ▽ 3
- ▼ 4

If Context is removed:

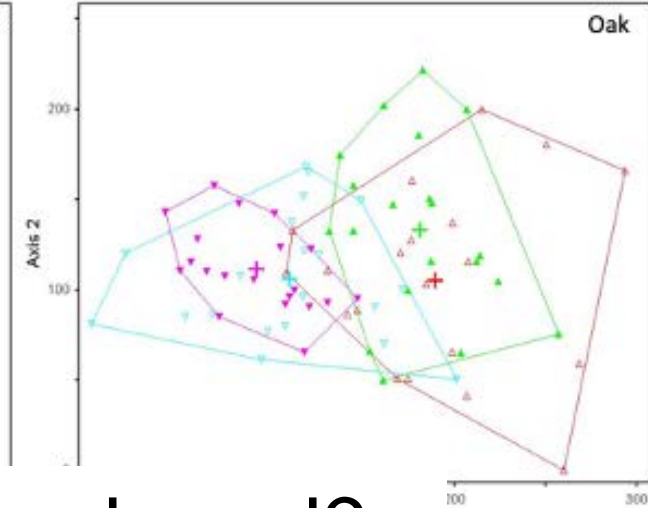
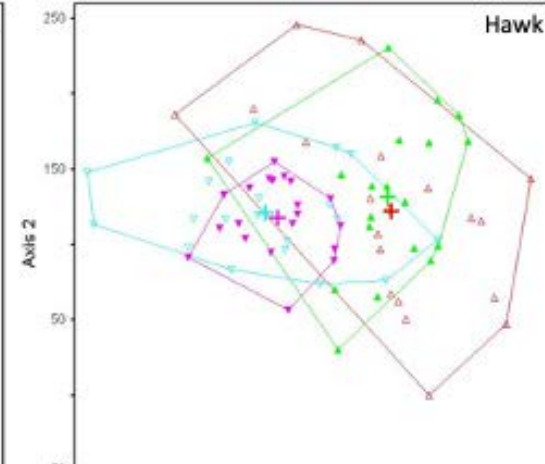
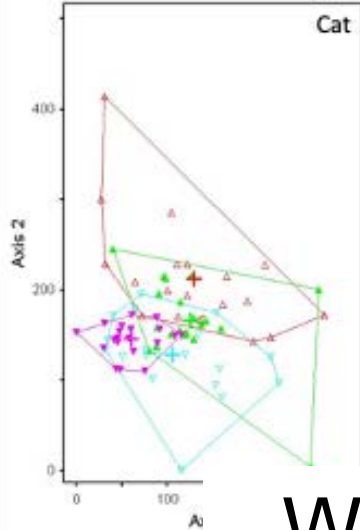
- Separation based on CVR
- General pattern of language progressing based on CVR
- Holds across contexts.



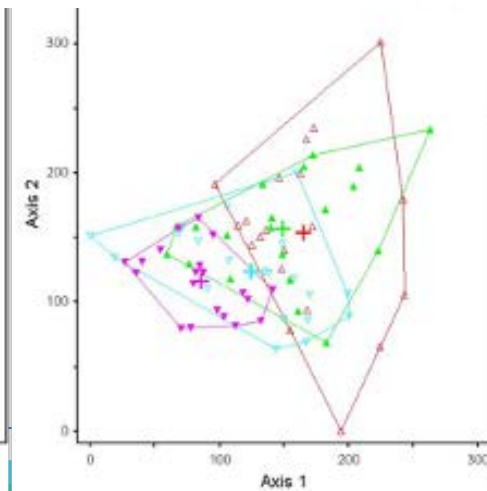
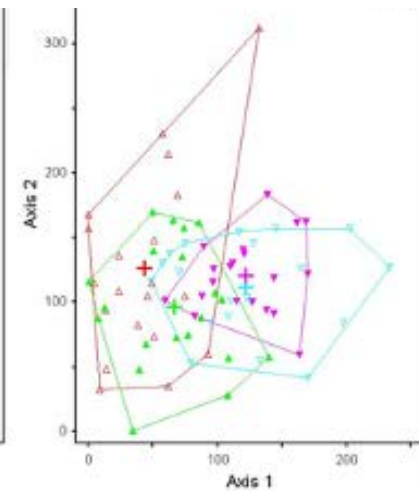
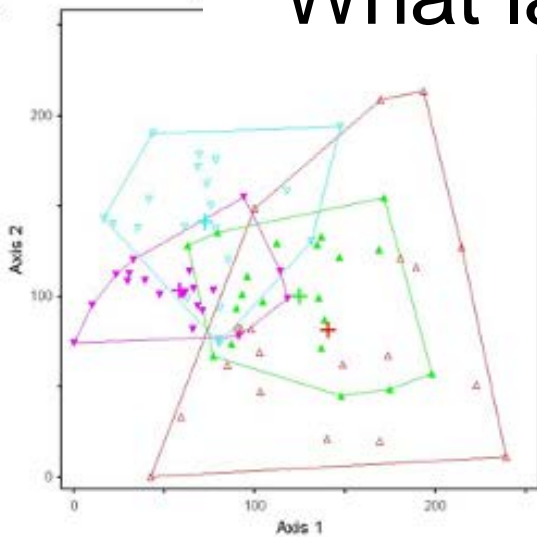


**CVR Level:**

- △ 1
- ▲ 2
- ▽ 3
- ▼ 4



What language is shared?



Rower

CVR Level:

- △ 1
- ▲ 2
- ▽ 3
- ▼ 4

# Text-based Content Analysis

Text analysis can determine predictive words within categories.

- Context-dependent words were present at each CVR level but were more related to Mass Balance reasoning at higher levels.
  - CVR1: *photosystem, water, sunlight, and rubisco*
  - CVR4: *cellular respiration and photosynthesis*
- Only higher levels of CVR shared words across contexts.
  - *lower, rate, net, less, change, and than*

# Conclusions

## What language is used to demonstrate skills in covariational reasoning?

- Context-dependent inputs and outputs.
- Comparative and summative language that are context-independent.

## What are the effects of context?

- Overall, context has a heavier influence than CVR level.
- Language becomes more specific as CVR increases.
- Mass Balance language progresses in each context and ends with similar language at the highest CVR levels.



# Contribution to Teaching

- Different contexts functionally build the same language, encouraging instructors to seek out multiple contexts for instruction and assessment.
- Focus on comparative and summative language that can be used to build explanations across contexts.

# Acknowledgements

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**Prompts are available at  
[beyondmultiplechoice.org](https://beyondmultiplechoice.org)**

Scott, E.E. et al. (2022) How students reason about matter flows and accumulations in complex biological phenomena: a learning progression for mass balance. *Journal of Research in Science Teaching*.  
<https://doi.org/10.1002/tea.21791>



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