Students’ Reasoning Tendencies about the Causal Dynamics of Ecosystems and the Impacts of MUVE vs. Non-MUVE Instructional Contexts

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What are our research questions?

Students make a different set of assumptions about the nature of the complex causal dynamics and systemic structure than ecosystems scientists do when reasoning about ecosystems dynamics (e.g. Grotzer & Basca, 2003; Grotzer et al., 2013; Grotzer & Solis, 2015; Hmelo-Silver, Pfeffer, & Malhotra, 2003). EcoMUVE (Metcalf et al, 2011) was designed to simulate ecosystems patterns and structural causalities.

RQ1: What reasoning tendencies were revealed in students’ initial explanations?

RQ2: Did students using the EcoMUVE and comparison curricula demonstrate gains in the proportion of complex causal responses?

RQ3: What was the effect of the use of the EcoMUVE on gains in complex causal responses, controlling for student and teacher-level fixed effects?
Where was the study conducted?

- 4 urban and suburban schools in New England
- ~60% Caucasian, 15% Black/African American, 15% Latino, 5% Asian
- All schools had sufficient technology resources to support the study
  - i.e. relatively affluent (FRPL ~25%)
Whom did we include in our study?

• Target Population
  – Middle School (grade 7&8) science students

• Sample
  – 5 Teachers included, students could opt-out
  – 263 Middle School students who were clustered in the 5 teachers
  – 142 Female, 121 Male

• Statistical Power Analysis
  – Given the sample size and number of clusters, we had a power of .80 to detect an effect size of 0.40 standard deviation units at a Type I error rate of .05.
What procedures did we employ?

- Block Cluster Randomized Experiment
  - Classes (two per teacher) randomly assigned to the treatment (n=10) or control (n=10) conditions
  - Students in the treatment used EcoMUVE pond curriculum
  - Students in the control used comparison curriculum

- Causal, Attitude, and Content Knowledge assessments prior to and after the intervention (before students or teachers knew the assignment).
What procedures did we employ?

- EcoMUVE Pond
  - Two week experience
  - Complex ecosystem mystery
  - Students took on roles and worked in teams

- Comparison
  - Two week
  - Co-taught with researcher
  - Environmental Detectives (GEMS Series – Lawrence Hall of Science)
What are our measures?

- **Outcome Variables**
  - Gain in the proportion of non-obvious responses
  - Gain in the proportion of spatially distant responses
  - Gain in the proportion of attentionally distant responses

- **Question Predictor**
  - EcoMUVE (1=yes, 0=no)

- **Covariates**
  - Pre proportion of non-obvious, spatially/attentionally distant responses
  - Pre Content Knowledge
  - Female (1=yes, 0=no)
  - Vector of Teacher Fixed Effects

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**Table 1. Descriptive statistics**

<table>
<thead>
<tr>
<th>Variable</th>
<th>EcoMUVE (n=127)</th>
<th>Compare (n=133)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>FEMALE</td>
<td>0.546</td>
<td>0.520</td>
<td>0.026</td>
</tr>
<tr>
<td></td>
<td>(0.499)</td>
<td>(0.502)</td>
<td></td>
</tr>
<tr>
<td>KNOW.PRE</td>
<td>23.248</td>
<td>22.945</td>
<td>0.303</td>
</tr>
<tr>
<td></td>
<td>(5.976)</td>
<td>(5.996)</td>
<td></td>
</tr>
<tr>
<td>TEACH1</td>
<td>0.195</td>
<td>0.283</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>(0.398)</td>
<td>(0.452)</td>
<td></td>
</tr>
<tr>
<td>TEACH2</td>
<td>0.120</td>
<td>0.118</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td>(0.327)</td>
<td>(0.324)</td>
<td></td>
</tr>
<tr>
<td>TEACH3</td>
<td>0.241</td>
<td>0.244</td>
<td>0.003</td>
</tr>
<tr>
<td></td>
<td>(0.429)</td>
<td>(0.431)</td>
<td></td>
</tr>
<tr>
<td>TEACH4</td>
<td>0.218</td>
<td>0.260</td>
<td>0.042</td>
</tr>
<tr>
<td></td>
<td>(0.414)</td>
<td>(0.440)</td>
<td></td>
</tr>
<tr>
<td>TEACH5</td>
<td>0.226</td>
<td>0.094</td>
<td>0.132**</td>
</tr>
<tr>
<td></td>
<td>(0.420)</td>
<td>(0.294)</td>
<td></td>
</tr>
<tr>
<td>NOPR.PRE</td>
<td>0.289</td>
<td>0.293</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>(0.151)</td>
<td>(0.165)</td>
<td></td>
</tr>
<tr>
<td>SDPR.PRE</td>
<td>0.007</td>
<td>0.006</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(0.033)</td>
<td>(0.026)</td>
<td></td>
</tr>
<tr>
<td>ADPR.PRE</td>
<td>0.046</td>
<td>0.036</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>(0.067)</td>
<td>(0.066)</td>
<td></td>
</tr>
<tr>
<td>NOPR.GAIN</td>
<td>0.165</td>
<td>0.129</td>
<td>0.036</td>
</tr>
<tr>
<td></td>
<td>(0.193)</td>
<td>(0.198)</td>
<td></td>
</tr>
<tr>
<td>SDPR.GAIN</td>
<td>0.048</td>
<td>0.052</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>(0.072)</td>
<td>(0.076)</td>
<td></td>
</tr>
<tr>
<td>ADPR.GAIN</td>
<td>-0.006</td>
<td>0.046</td>
<td>0.040***</td>
</tr>
<tr>
<td></td>
<td>(0.078)</td>
<td>(0.102)</td>
<td></td>
</tr>
</tbody>
</table>

*Note: **p<0.01, ***p<0.001*
What data analyses did we conduct?

- Multi-level and fixed-effects models
  - Checked for linearity
  - Usual residual assumptions

- RQ2:
  \[ \text{e.g., NOPR.GAIN}_{ij} = \beta_0 + \varepsilon_{ij} \]
  \[ \beta_0 = \pi_{00} + \xi_{0j} \]

- RQ3:
  \[ \text{e.g., NOPR.GAIN}_{ij} = \alpha + \beta_1 \xi_{ij} + \delta_{ij} + \omega \tau_j + \varepsilon_{ij} \]
RQ1: Trends in initial responses

- Low proportion of complex initial responses were in the expected direction of novice type responses.

- Gains in proportion of complex responses supports prior work (Grotzer et al., 2013).
RQ2: Both groups showed gains

Table 2. Null multilevel models predicting gain in proportion of complex causal explanations for students who used the comparison curriculum.

<table>
<thead>
<tr>
<th>Gain Scores</th>
<th>Non-Obvious</th>
<th>Spatial Distance</th>
<th>Attentional Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.129***</td>
<td>0.053***</td>
<td>0.046***</td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
<td>(0.009)</td>
<td>(0.009)</td>
</tr>
</tbody>
</table>

Variance Components
- Residual: 0.196822, 0.0739252, 0.1018579
- Intercept (Teacher): 0, 0.01476279, 0

Observations: 127, 127, 127
-2LL: -52.45532, -297.789, -219.7706

Table 3. Null multilevel models predicting gain in proportion of complex causal explanations for students who used the EMVE pond unit.

<table>
<thead>
<tr>
<th>Gain Scores</th>
<th>Non-Obvious</th>
<th>Spatial Distance</th>
<th>Attentional Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.165***</td>
<td>0.048***</td>
<td>0.006</td>
</tr>
<tr>
<td></td>
<td>(0.017)</td>
<td>(0.006)</td>
<td>(0.009)</td>
</tr>
</tbody>
</table>

Variance Components
- Residual: 0.192097, 0.0720962, 0.07770718
- Intercept (Teacher): 0, 0, 0.003656026

Observations: 133, 133, 133
-2LL: -61.39714, -322.07681, -301.8554

Cells are estimates (s.d.)
Note: ***p<0.001
RQ3: Comparison showed more gains in attentional distance

Table 4. OLS regression models predicting effect of the use of the EcoMUVE on the gain in proportion of complex causal explanations, controlling for student and teacher fixed-effects.

<table>
<thead>
<tr>
<th></th>
<th>Non-Obvious</th>
<th>Spatial Distance</th>
<th>Attentional Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>EcoMUVE</td>
<td>0.026</td>
<td>-0.004</td>
<td>-0.054***</td>
</tr>
<tr>
<td></td>
<td>(0.025)</td>
<td>(0.009)</td>
<td>(0.012)</td>
</tr>
<tr>
<td>Student Fixed-Effects</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Teacher Fixed-Effects</td>
<td>✔</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>0.102*</td>
<td>0.067***</td>
<td>0.043</td>
</tr>
<tr>
<td></td>
<td>(0.058)</td>
<td>(0.023)</td>
<td>(0.028)</td>
</tr>
<tr>
<td>Observations</td>
<td>260</td>
<td>260</td>
<td>260</td>
</tr>
<tr>
<td>R²</td>
<td>0.031</td>
<td>0.052</td>
<td>0.108</td>
</tr>
</tbody>
</table>

*Cells are estimates (s.d.)*

Note: *p<0.05, ***p<0.001
What are possible threats to validity?

• Internal Validity
  – Roles may have been related to student gains
  – Researchers tracked fidelity of implementation

• External Validity
  – Teachers self-selected
  – Low FRPL
  – High technology infrastructure
What are the take-aways?

- Both conditions revealed the initial assumptions that were consistent with the trends seen in the literature.
- Both conditions made significant gains.
- Comparison condition performed as well on non-obvious and spatial distance and *better* on action at an attentional distance.
  - Students navigate through the MUVE with ease.
  - Students don’t experience distance in the same way in the MUVE.
  - *MORE RESEARCH*
We would like to express our appreciation to the teachers and students who allowed us to collect data on their reasoning patterns. Thank you to David Jeong and Saida Lynneth Solis for assistance coding data. Our deep appreciation goes to Dr. Kathleen Weathers at the Cary Institute for Ecosystems Studies for her many contributions to the thinking behind this work.

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Thank you!

Questions?

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