Using Science Simulations to Promote and Assess Complex Science Learning

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“Formative assessment is a process used by teachers and students during instruction that provides feedback to adjust ongoing teaching and learning to improve students’ achievement of intended instructional outcomes.”
Calipers II: Using Simulations to Assess Complex Science Learning

Goals

• Develop formative and benchmark simulation-based assessments of science knowledge for key content in physical and life science and for science inquiry strategies.

• Enhance formative assessment simulation modules with immediate, individualized feedback, coaching, and reflection activities.

• Develop and document technology-based assessment designs and exemplars that take advantage of simulation environments to provide assessments of science standards for formative and summative purposes.
Calipers II Goals (cont’d)

• Document the technical infrastructure and re-usable designs and processes employed.

• Provide evidence of the technical quality, feasibility, and usability of the new assessments.

• Study the influence of formative assessments on complex science and inquiry learning.

• Link the enlarged collection of Calipers II benchmark and formative, assessment to national science standards and the AAAS item clusters.
Technology Affordances

• Animations of dynamic system phenomena
  – Can observe and review

• Simulation-based investigations
  – Iterative design
  – Virtual data collection
  – Conducting and saving multiple trials
  – Multimodal information and data displays

• Multiple, overlapping, simultaneous representations

• Scientific “tools of the trade”
  – Simulations, graphs, tables, zoom, drawing, highlighting

• Immediate, contingent feedback and hints, adaptive scaffolding

• Bayes Nets within simulations to assess proficiencies
Multiple Modes of Representation
Active Inquiry

- Organism box shows icons that appear and disappear
- Graph shows size of population over time.
- Data inspector shows population for one point on graph.
- Table shows population at start, end, and point selected by data inspector.
SimScientists Assessments
Embedded & Benchmark

- Regular Instruction
  - Embedded Assessment + Reflection Activity

- Regular Instruction
  - Embedded Assessment + Reflection Activity

- Regular Instruction
  - Embedded Assessment + Reflection Activity

- Regular Instruction
  - Benchmark Assessment
Embedded Assessment Components

Online assessment with feedback & coaching

STUDENT PROGRESS REPORT

TEACHER REPORT

Reflection Activities
NGSS Standards Assessed

- Cross-cutting concepts
  - Systems and System Models
  - Energy flow
- Science Practices
  - Using models
  - Investigations
- Ecosystem core ideas
## SimScientists Ecosystems System Model

<table>
<thead>
<tr>
<th>Model Level</th>
<th>Descriptions</th>
<th>Content Targets</th>
<th>Science Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component</td>
<td>What are the components of the system and their rules of behavior?</td>
<td>Every ecosystem has a similar pattern of organization with respect to the roles (producers, consumers, and decomposers) that organisms play in the movement of energy and matter through the system. (NGSS: LS2.A—Interdependent Relationships in Ecosystems)</td>
<td>Analyzing and Interpreting Data</td>
</tr>
<tr>
<td>Interaction</td>
<td>How do the individual components interact?</td>
<td>Matter and energy flow through the ecosystem as individual organisms participate in feeding relationships within an ecosystem. (NGSS: LS2.B—Cycles of Matter and Energy Transfer in Ecosystems)</td>
<td>Developing &amp; Using Models; Analyzing and Interpreting Data</td>
</tr>
<tr>
<td>Emergent</td>
<td>What is the overall behavior or property of the system that results from many interactions following specific rules?</td>
<td>Interactions among organisms and among organisms and the ecosystem’s nonliving features cause the populations of the different organisms to change over time. (NGSS: LS2.C—Ecosystems Dynamics, Functioning and Resilience)</td>
<td>Planning and Carrying Out Investigations; Analyzing and Interpreting Data</td>
</tr>
</tbody>
</table>
# Atoms & Molecules Target System Model

<table>
<thead>
<tr>
<th>Component</th>
<th>Atoms and Molecules</th>
<th>Skill</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><img src="image" alt="Nitrogen" />, <img src="image" alt="Water Vapor" />, <img src="image" alt="Argon" /></td>
<td>Observe</td>
</tr>
<tr>
<td>Interaction</td>
<td><strong>Speed – Spacing – Collisions</strong></td>
<td></td>
</tr>
<tr>
<td>Emergent</td>
<td><strong>Boiling &amp; Melting Point – States of Matter</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td><img src="image" alt="Nano Viewer" />, <img src="image" alt="Boiling Point" />, <img src="image" alt="Melting Point" /></td>
<td>Measure &amp; Investigate</td>
</tr>
</tbody>
</table>
Demo:
SimScientists
Formative Assessment Features

• Immediate, individualized feedback and coaching
• Reflection activities that address students’ needs, promote transfer and scientific discourse
• Timely information that teachers can use
Can you do better than Dr. A? Design three trials so that both the shrimp and alewife populations survive for 20 years.

- Use the sliders to change the starting numbers of shrimp and alewife.
- Click RUN to see what happens.
- When you have saved 3 trials in which shrimp and alewife survive for 20 years, click NEXT.

In the highlighted trials, all three organisms did not survive for 20 years. Here are starting values that will allow all the organisms to survive 20 years:

- shrimp 15, alewife 15
- shrimp 40, alewife 15
- shrimp 50, alewife 20

Use one pair of starting values for each highlighted trial. Then click RUN.
The truck is moving at 10 km/h. Now the fire chief wants you to show how to make the truck’s speed stay the same.

- Draw the forward and backward forces so that the truck’s speed stays the same.
- Click RUN to observe how the truck’s speed changes with the forces you selected.
- If the forces made the truck’s speed stay the same, click SAVE TRIAL.
- If not, click CHANGE STARTING VALUES and try again.
## Progress Reports to Students

### Report for Mountain Lake - Predator Prey

#### Populations
- Interactions between organisms and between organisms and the ecosystem's nonliving features cause the populations of the different organisms to change over time.

#### Conduct
- Conducting investigations involves carrying out scientific investigations using appropriate tools and techniques.

#### Identify
- Identifying Science Principles focuses on students' ability to recognize, recall, define, relate, and represent basic science principles. The practices assessed in this category draw on declarative knowledge or "knowing that."

#### Design
- Designing investigations involves asking questions, planning investigations and evaluating experimental design.

#### Analyze
- Identifying patterns involves summarizing patterns in data, analyzing which data are relevant and drawing conclusions by relating patterns in data to theoretical models.
## Progress Reports to Teachers

**Summary Report: Mountain Lake - Food Web**

### ASSESSMENT
- Mountain Lake - Food Web

### CLASS
- Period 7

### Content

<table>
<thead>
<tr>
<th>Content</th>
<th>NH Needs Help</th>
<th>P Making Progress</th>
<th>OT On Track</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roles</td>
<td>12 (46%)</td>
<td>4 (15%)</td>
<td>10 (38%)</td>
</tr>
<tr>
<td>Interactions</td>
<td>15 (58%)</td>
<td>4 (15%)</td>
<td>7 (27%)</td>
</tr>
<tr>
<td>Inquiry</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Identifying</td>
<td>15 (58%)</td>
<td>5 (19%)</td>
<td>6 (23%)</td>
</tr>
<tr>
<td>Using</td>
<td>10 (38%)</td>
<td>5 (19%)</td>
<td>11 (42%)</td>
</tr>
</tbody>
</table>

**NH** = needs help  
**P** = making progress  
**OT** = on track
Grouping Recommendations for Classroom Reflection Activity

### Reflection Activity PDF

Group A students needed little help on either roles or interactions.
Group B students needed help with interactions, but not with roles.
Group C students needed help with understanding the roles of organisms in an ecosystem.

<table>
<thead>
<tr>
<th>Student</th>
<th>Refl Gr.</th>
<th>Roles</th>
<th>Interactions</th>
<th>Identifying</th>
<th>Using</th>
</tr>
</thead>
<tbody>
<tr>
<td>Student 1</td>
<td>C</td>
<td>P</td>
<td>NH</td>
<td>NH</td>
<td>OT</td>
</tr>
<tr>
<td>Student 1</td>
<td>C</td>
<td>NH</td>
<td>NH</td>
<td>NH</td>
<td>NH</td>
</tr>
<tr>
<td>Student 3</td>
<td>A</td>
<td>OT</td>
<td>OT</td>
<td>OT</td>
<td>OT</td>
</tr>
<tr>
<td>Student 4</td>
<td>A</td>
<td>OT</td>
<td>OT</td>
<td>OT</td>
<td>OT</td>
</tr>
<tr>
<td>Student 5</td>
<td>C</td>
<td>NH</td>
<td>NH</td>
<td>NH</td>
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<tr>
<td>Student 6</td>
<td>C</td>
<td>NH</td>
<td>NH</td>
<td>NH</td>
<td>P</td>
</tr>
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<td>Student 7</td>
<td>C</td>
<td>P</td>
<td>NH</td>
<td>NH</td>
<td>P</td>
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<td>Student 8</td>
<td>C</td>
<td>NH</td>
<td>NH</td>
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<tr>
<td>Student 9</td>
<td>C</td>
<td>NH</td>
<td>OT</td>
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<td>P</td>
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<tr>
<td>Student 10</td>
<td>B</td>
<td>OT</td>
<td>NH</td>
<td>OT</td>
<td>P</td>
</tr>
</tbody>
</table>
Classroom Reflection Activity

- Formative use of assessment results
  - Students assigned to teams based on embedded results
- Transfer to different, more complex system
- Jigsaw structure
  - Allows differentiated instruction via tasks of varying difficulty
  - Promotes small and large group discourse and collaboration
- Guidance for teacher
  - Teacher review of key points in simulation
  - What to look for during group work and questions to pose in response
  - Posters and presentations
  - Evaluation of posters and presentations by students and teachers
Workshop Reflection Activity

For each ecosystem

– Divide into 3 groups
  • Distribute Interaction Cards (3 groups)
    – Identify roles of organisms as consumers or producers
  • Draw arrows showing flow of matter and energy
  • Answer riddles
  • Make up a new riddle

– Present ecosystem
  • Identify two consumers, one producer
  • Show the energy and matter arrows for each

– Present riddle
Transfer to new, more complex ecosystem
Calipers II
Reflection Activities: Ecosystems
Calipers II
Reflection Activities: Ecosystems
Ecosystem Benchmark Assessment: Assess Transfer to New Ecosystem

Make a food web diagram. Draw arrows to show the transfer of matter between organisms.

- To draw an arrow, click and drag from one dot to another dot.
- To delete an arrow, double click on it.

Be sure to include each organism in the food web.

You can review the animation and then return to this diagram.
### Summary Benchmark report

#### Content

<table>
<thead>
<tr>
<th>Role</th>
<th>Below Basic</th>
<th>Basic</th>
<th>Proficient</th>
<th>Advanced</th>
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<tbody>
<tr>
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<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>Interactions</td>
<td>3 (100%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

Matter and energy flow through the ecosystem as individual organisms interact with each other. Food web diagrams indicate the feeding relationships among organisms in an ecosystem. All ecosystems have a flow of energy from a nonliving source, to producers, to consumers.

#### Inquiry

<table>
<thead>
<tr>
<th>Identify</th>
<th>Below Basic</th>
<th>Basic</th>
<th>Proficient</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (33%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>2 (67%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Use</th>
<th>Below Basic</th>
<th>Basic</th>
<th>Proficient</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (33%)</td>
<td>2 (67%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Design</th>
<th>Below Basic</th>
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<th>Proficient</th>
<th>Advanced</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (33%)</td>
<td>2 (67%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
</tbody>
</table>

#### Detailed Report by Student and Target

<table>
<thead>
<tr>
<th>Student</th>
<th>Roles</th>
<th>Interactions</th>
<th>Populations</th>
<th>Identify</th>
<th>Use</th>
<th>Design</th>
<th>Conduct</th>
<th>Analyze</th>
<th>Evaluate</th>
<th>Communicate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simmons85, Sara85</td>
<td>BB</td>
<td>BB</td>
<td>A</td>
<td>BB</td>
<td>BB</td>
<td>BB</td>
<td>B</td>
<td>BB</td>
<td>BB</td>
<td>A</td>
</tr>
<tr>
<td>Simmons86, Sara86</td>
<td>BB</td>
<td>BB</td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>BB</td>
<td>BB</td>
<td>A</td>
</tr>
<tr>
<td>Simmons87, Sara87</td>
<td>BB</td>
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<td>A</td>
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<td>B</td>
<td>B</td>
<td>BB</td>
<td>BB</td>
<td>B</td>
</tr>
</tbody>
</table>
SimScientists Research Findings

• AAAS review of alignment of content and inquiry targets with national and state standards
• Cognitive labs
• Classroom feasibility testing
• Pilot testing
• Field testing
  – EAG study involving 4 states, 28 districts, 58 teachers, 6,000 students
  – Calipers II and MASS, 3 states, 3 districts, 28 teachers, 2,500 students
SimScientists Research Findings

• Technical quality
• Implementation evaluation
• Effects of embedded on summative simulation benchmark and conventional posttest
“I think that [students] are way more engaged. When I told them that we were going next door to work on the computers again, they all seemed pretty excited to go next door and work on it.”
CRESST Case Study Interviews

• “…I like that kind of feedback when it doesn’t just go to the next page and they don’t know whether they did it right or not.”

• “…Yes, the science content is really being tested. Students are asked to conduct experiments, investigate, and draw conclusions and to use scientific skills. Students are not able to guess on the multiple choice questions because it probes them until they choose the right answer. Students are also taught about food webs in one biome and they are tested on another biome.”
CRESST Evaluation Conclusions

• Observations showed that students were actively engaged most of the time during assessments.

• Both teachers and students generally believed that the SimScientists program was beneficial to learning.

• Teachers found the automatically scored, immediate feedback—especially the reports generated by the questions—helpful to students. The instant reports allowed teachers to easily see which questions students had the most difficulty with so that they could tailor their lessons accordingly.
CRESST Evaluation Conclusions

• Teachers collectively agreed that the simulation assessments had greater benefits than traditional paper-and-pencil tests because of the simulation’s instant feedback, interaction, and visuals.
• Teachers agreed that the assessments would be useful in measuring their individual state standards.
Current Findings

The SimScientists simulation-based assessments

- Measure constructs not tested well by static modalities
- Can discriminate measures of inquiry and content
- The curriculum-embedded assessments seem to have positive effects on student learning
- The summative benchmark assessments have sufficient technical quality to be components of a state science assessment reporting system
Summary of Technical Quality Analyses

• Correlations
  – Moderate correlations between benchmark and post test (0.57–0.64)
  – Correlations between content and inquiry are higher on the post test than the benchmark

• Gap analysis for ELLs and SWDs
  – Both groups perform better than expected on the benchmark assessment (based on their post test ability estimates)

• Reliability
  – High for all measures (coefficient alpha: 0.83–0.89)

• Effect of the treatment
  – Small, significant effect on the post test (0.07–0.08)
  – Moderate, significant effect on the benchmark (0.3–0.4)
  – Larger effect on benchmark inquiry than content (up to 0.58)
Balanced, Multilevel Assessment System Models

- Reporting benchmark results alongside district and state data
- Matrix sampling of short “signature” tasks from different topics
Side-by-Side Model
Signature Task Model

State Test Forms

Matrix Sampling

Simulation-based task item bank

Specifications and Simulation environments

Simulation-Based Classroom Assessments
Continuing Research

• Study vertically aligned simulation based assessment suites for life and physical science of
  – Classroom assessments
    • curriculum embedded assessments (for formative purposes)
    • benchmark assessments (for summative purposes)
  – Large scale assessments
    • signature tasks (for summative purposes)

• Create simulation-based curriculum supplements
Contact information

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