WISE Ways to Strengthen Inquiry Science Learning

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Opportunities to expand inquiry and project learning: Expanding data sources & more powerful methods
Mentored by Richard Atkinson

Used Markov Chains to model learning of mathematical tasks

Tested theories about short and long term memory

-Learned the value of distributed practice
Mentored by Lee Cronbach

Used methods that are common in EDM today including:

- Factor analysis to test ideas about human abilities
- Complex regression models to analyze the scalability of educational treatments, identify aptitude-treatment-interactions
- Learned importance of valid outcome measures and powerful conceptual frameworks
Studied with Jean Piaget

Used interviews to explore student ideas about complex scientific phenomena.

Was teased about my interest in, *The American Question*: How are these ideas learned?

- Learned how slight variations in interview questions often yielded new ideas. Evidence for the repertoire of ideas students bring to science classes.
Today partnership!
Thank you

Lauren Applebaum, Jonathan Lim-Breitbart, Jennifer King Chen, Libby Gerard, Geoffrey Kwan, Beth McBride, Kevin McElhaney, Mario Martinez, Kihyun Ryoo, Jim Slotta, Charissa Tansomboon, Hiroki Terashima, Jonathan Vitale, Eliane Weise, and the Linn Research Group
Goal: Promote Knowledge Integration

How can we design instruction, measure progress, and guide students to continuously develop more integrated, coherent, and generative understanding of complex scientific phenomenon?
Seasons depend on whether the earth is facing the sun. The earth is tilted so sometimes it faces the sun and sometimes it doesn’t.

The earth is closer to the sun in Summer.

The seasons are caused by the hours of daylight. In summer the days are longer; in winter they are shorter.

Seasons depend on whether the earth is facing the sun. The earth is tilted so sometimes it faces the sun and sometimes it doesn’t.
Students have multiple, culturally relevant ideas about complex science topics.
Talk to your neighbor

How do you elicit student ideas?
How do you build on them?
Knowledge Integration PATTERN

I think X because...
Moreover...
However...

Donnelly KI Model, 2014; Linn & Eylon, 2011; Matuk KI Model, 2012;
The *Mitosis* unit

Unit activity sequence

- **What is cancer?**
- **Phases of cell division**
- **Trade off, side effects**
- **Investigate 3 potential treatments**
- **Side effects of cancer treatment**

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**ELICIT, ADD**

- Nerve Cells
- Liver Cells
- Muscle Cells
- Skin Cells

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**ORGANIZE**

- Useful
- Maybe useful
- NOT useful

**DISTINGUISH**

- NORMAL CELL
- TREATED CELL

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**REFLECT**

Based on your findings, which plant would you recommend as a cancer medicine? Use the observations you organized to explain your reasons.

**SAVE RESPONSE**

We recommend Plant A because the medicine stopped the chromosomes from duplicating, and this would stop cell division.
Web-based Inquiry Science Environment
Logs student data and guides in real time

WISE captures student drawings, concept maps, interactions with models and simulations, graphs, essays

WISE designers can write scripts to analyze responses and
◦ We research design of optimal guidance for the response
◦ We explore branching students to alternative conditions

WISE collaborates with ETS to use c-rater ML
◦ c-rater scores essays for knowledge integration
◦ We research design of optimal guidance based on the score
Analyze Drawing of Chemical Reaction
Automated Knowledge Integration Guidance

- Good start. You have correctly created 2 frames that represent the reactants and products of the methane combustion reaction.
- Can atoms in the reaction be spontaneously CREATED OR DESTROYED?
- Reread the directions and revisit steps 3.6-3.8. Make an improved drawing.

Nice try! Now review the visualization in Step 3.3 to find out what plants do with the extra glucose and revise your diagram.

Analyze short essays
Explore best way to guide knowledge integration

“I like when there is writing because with typing it feels like I can explain more instead of...just doing multiple choice, because then its kind of like I want to explain it really bad but you can only put an answer.”

-- 7th grade study participant

Mary heard that growing plants on the roof could lower the house’s energy usage. But, Mary does not understand how plants would help.

Write an energy story to explain to Mary what happens from energy in the sun in the picture. How could growing plants on the roof reduce the house’s energy usage?
The sun's energy went to the plants and the plants absorbed the light energy. The energy went through the walls to be stored. It is transformed when it goes through the plants and down the wall.

The energy is absorbed by the plants, this energy is converted to heat energy. Which insulates the house.

When they grow this gives the house shade and the house saves money on electricity.

The energy transfers because the roof attracts the sun.

The energy is stored in the plant like solar panels and the plant can transform the energy to chemical for electricity.

The energy comes from pre-existing energy that transforms, energy is stored in molecules. Energy explodes and the chemicals inside change.
Where does energy come from?

How does energy change?

Why are plants important?

WISE Photosynthesis
How effective is c-rater in applying the knowledge integration rubric?

<table>
<thead>
<tr>
<th>Score</th>
<th>Criteria</th>
<th>Examples from GreenRoof</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Off Task</td>
<td>IDK</td>
</tr>
<tr>
<td>2</td>
<td>Non-normative; incomplete</td>
<td>The sun gives electricity to the plants</td>
</tr>
<tr>
<td>3</td>
<td>Partial Link; mix of norm and non-norm</td>
<td>Plants turn the light energy into food</td>
</tr>
<tr>
<td>4</td>
<td>Full link between two norm ideas</td>
<td>Energy from the sun is transformed into heat energy when it reaches the roof</td>
</tr>
<tr>
<td>5</td>
<td>Two full links</td>
<td>Energy from sun is transformed into heat when it hits the roof, but plants can turn the light into chemical energy</td>
</tr>
</tbody>
</table>

Building a c-rater model

- Collaboration with ETS
  - Uses supervised machine learning
  - Takes 1000+ human scores per item as input
  - Currently have 22 scored essays, more forthcoming

Model Building

Feature extraction

- "The dog jumped in..." - 3
- "They went to the movies..." - 1
- "It is time to leave..." - 6

- word n-grams
- character n-grams
- syntactic dependencies
- semantic dependencies
- length

?
Feature Classes

- word \(n\)-grams
- character \(n\)-grams
- syntactic dependencies
- semantic dependencies
- length
Word \(n\)-grams

**Tokenization**
- Text broken into units
- Words separated from punctuation
- Contractions teased apart

**\(n\)-grams**
\(n\)-word sequences (for \(n = 1\) to 2)

- \(n = 1\): {"the": 1, "graph": 1, "clearly": 1, "shows": 1, "an": 1, "increase": 1, ":": 1}
- \(n = 2\): {"the graph": 1, "graph clearly": 1, "clearly shows": 1, "shows an": 1, ...}

**Input Response**
- The graph clearly shows an increase.

**Tokenize**
- "the", "graph", "clearly", "shows", "an", "increase", ":"

**\(n\)-grams**
- \(n = 1\): {"the": 1, "graph": 1, "clearly": 1, "shows": 1, "an": 1, "increase": 1, ":": 1}
- \(n = 2\): {"the graph": 1, "graph clearly": 1, "clearly shows": 1, "shows an": 1, ...}
Character $n$-grams

- Same idea as word $n$-grams, but for "characters", i.e., letters, spaces, punctuation, etc.
- For $n = 2$ to 5
- Case-sensitive!
Syntactic Dependencies

- Syntactic relationships between words

  - Main verb usually follows subject immediately, but other content can intervene
  - n-gram features alone would not capture all of these relationships
Semantic Dependencies

- Semantic relationships between words

  the graph clearly shows an increase

  - “graph”: “agent” of ‘shows’
  - “increase”: theme/patient of ‘shows’
  - Note: “graph” is also the subject and “increase” the object of the verb, leading to the question...
Length

Length of response is determined by the log of the # of characters

\[ \log(\text{chars}) \]

chars
- alphanumeric: "a", "B", "3"
- whitespace: " ", "\t" (tab character)
- punctuation: ".", ","
Model Building

- Uses support vector regression
- Can deal with non-linear relationships

Feature extraction → ML

- It is time to leave...
- They went to the movies...
- The dog jumped in...
Example Item Mitosis
Small sample size, kappa = .62

<table>
<thead>
<tr>
<th>Human (Rows)</th>
<th>Automated (Columns)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>22</td>
<td>8</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>30</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>131</td>
<td>50</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>188</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>48</td>
<td>89</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>142</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>1</td>
<td>8</td>
<td>6</td>
<td>0</td>
<td>0</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>N</td>
<td>30</td>
<td>188</td>
<td>149</td>
<td>11</td>
<td>1</td>
<td>1</td>
<td>377</td>
</tr>
</tbody>
</table>

Students asked to explain transmission of Cystic Fibrosis. Found that “small “ sample means miss some synonyms such as DNA and genes.

Will this still be powerful enough?

Example of Knowledge Integration Guidance  Score = 2

<table>
<thead>
<tr>
<th>Student Example</th>
<th>KI score</th>
<th>Knowledge Integration Guidance</th>
<th>Typical Teacher Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>the sun would go directly to it the rain would give it water and the chloroplast would take it in.</td>
<td>2</td>
<td>Good start. Now, let’s think about energy. How do plants use energy from the sun – what is the process? Compare what you think with what you see in Step 2.14. Then, use your own words to write a new story below.</td>
<td>Incorrect. Redo.</td>
</tr>
<tr>
<td></td>
<td>Non-normative; vague</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Most scores off by 1 at most, meaning that the guidance that is assigned is generally relevant.
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<th>KI score</th>
<th>Knowledge Integration Guidance</th>
<th>Typical Teacher Guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>the energy comes from the sun. the light energy from the sun goes to the plant and the chloroplast in the plant cells absorb the light to make food for themselves. the light energy changes then to usable energy for the plants.</td>
<td>4 One full scientific link between 2 ideas</td>
<td>Nice thinking. Now, compare what happens when sunlight energy hits the roof and when it hits plants on the roof. Check out Step 2.3 to gather some ideas. Add to your story below.</td>
<td>Add detail. Where do plants store energy?</td>
</tr>
</tbody>
</table>
Encountered an obstacle

Some students discounted computer guidance. Added personalization and an explanation

<table>
<thead>
<tr>
<th>Student Example</th>
<th>KI score</th>
<th>Auto KI Guidance 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>the sun would go directly to it, the rain would give it water, and the chloroplast would take it in.</em></td>
<td>2. Incomplete</td>
<td><em>Jess and Owen</em>, expand your story. <em>How does the energy change inside the chloroplast?</em> Check out <em>&lt;here&gt;</em> for a hint. Then, revise your story below.</td>
</tr>
</tbody>
</table>
The energy from the light will only stay with the plant and will not transfer for your house's energy and it will not reduce energy cost.

The light energy is absorbed by the plant is turned into chemical energy and used by the plants to make glucose and produce oxygen.
The reason they have plants on the roof is because the plants get energy from the sun so they have to use less energy in their house.

The energy from the sun taken from the plants is transformed into chemical energy which gives the house energy.

Gerard, Tansomboon, & Linn. [ESERA Proceedings 2015; AERA 2016].
Research shows c-rater scores adequate Better than typical, specific guidance similar to expert teacher guidance

Knowledge integration guidance promotes distinguishing ideas

Better than typical guidance

Better than specific on posttest

Comparable to expert teacher who knows the unit.


<table>
<thead>
<tr>
<th>Meta-analysis Guidance Comparison</th>
<th>Meta-analysis Significant Moderators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automated Adaptive Guidance</td>
<td>Typical Instruction p&lt;.001</td>
</tr>
<tr>
<td></td>
<td>Prior knowledge</td>
</tr>
<tr>
<td></td>
<td>Low/medium benefits</td>
</tr>
<tr>
<td>Enhanced Adaptive Automated</td>
<td>Simple Adaptive Automated</td>
</tr>
<tr>
<td>Guidance (such as Knowledge</td>
<td>Guidance p&lt;.001</td>
</tr>
<tr>
<td>Integration)</td>
<td>Prior knowledge</td>
</tr>
<tr>
<td></td>
<td>Low/medium benefits</td>
</tr>
<tr>
<td></td>
<td>Design Features</td>
</tr>
<tr>
<td></td>
<td>Greater benefit for self-monitoring guidance &amp; Generating activities</td>
</tr>
</tbody>
</table>

Automated c-raterML Guidance

Conclusions

C-raterML is moderately successful in scoring short science essays for knowledge integration [Kappa .66-.91]. These scores enable a research program to investigate value of multiple designs for knowledge integration guidance:

- Research to date, documents benefits of knowledge integration guidance compared to typical, expert teacher, or specific guidance.
Next Steps for automated guidance: Diagnose uninformative essay responses

Identify students consistently giving these types of responses.

<table>
<thead>
<tr>
<th>I don’t know</th>
<th>Non-words</th>
<th>Off-task</th>
<th>Needs elaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>i have no idea?</td>
<td>khnv vb</td>
<td>Stuff</td>
<td>they could be in different places.</td>
</tr>
<tr>
<td>i don't know sadly!!!</td>
<td>i hgfjdks</td>
<td>hi</td>
<td>The model will change.</td>
</tr>
<tr>
<td>idk</td>
<td>njhyfr68uvuh</td>
<td>I’m done</td>
<td>the natural selection leads like a boss.</td>
</tr>
</tbody>
</table>

Action:
Encourage refinement
Alert teacher
Guiding Student Interactions with Models and Graphs

Conclusions: building on constructivist research

The knowledge integration design principles, assessments, and guidance build on extensive research in the learning sciences.

This framework guides use of EDM to *discover meaningful patterns in complex data*
Conclusions

EDM methods along with powerful, virtual or experiential investigations, show promise for increasing impact and use of inquiry instruction

◦ Can personalize guidance for students using models to distinguish among ideas
◦ Can diagnose ways to prompt learners to revise ideas in drawings, essays and concept maps
◦ Can identify which students need to revisit material, taking advantage of distributed practice
Conclusions

These approaches could be used to guide large groups of students as they conduct inquiry investigations in varied contexts.

- Maker spaces, Museums

Can these insights also apply to MOOCs, electronic textbooks, LMS courses?
My Questions.......  
What are the implications of these findings for MOOCs, electronic textbooks, and LMS courses? 
What are other ways to extend our support for inquiry learning?
WISE is Free and Available

mclinn@berkeley.edu
Join the WISE Developers Community
https://github.com/WISE-Community/WISE
Many students use WISE
Many teachers use WISE
WISE use around the world
Servers in Taiwan, China, Argentina

Research groups in
Belgium
Canada
Germany
Thailand