WISE Ways to Strengthen Inquiry Science Learning

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Opportunities to expand inquiry and project learning: Expanding data sources & more powerful methods

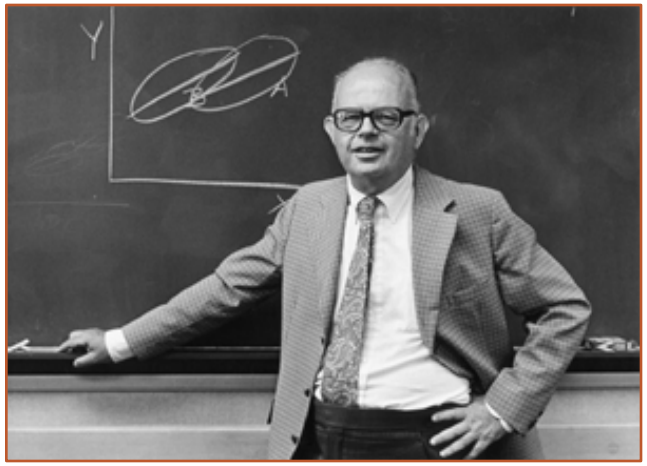
Mentored by Richard Atkinson

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?

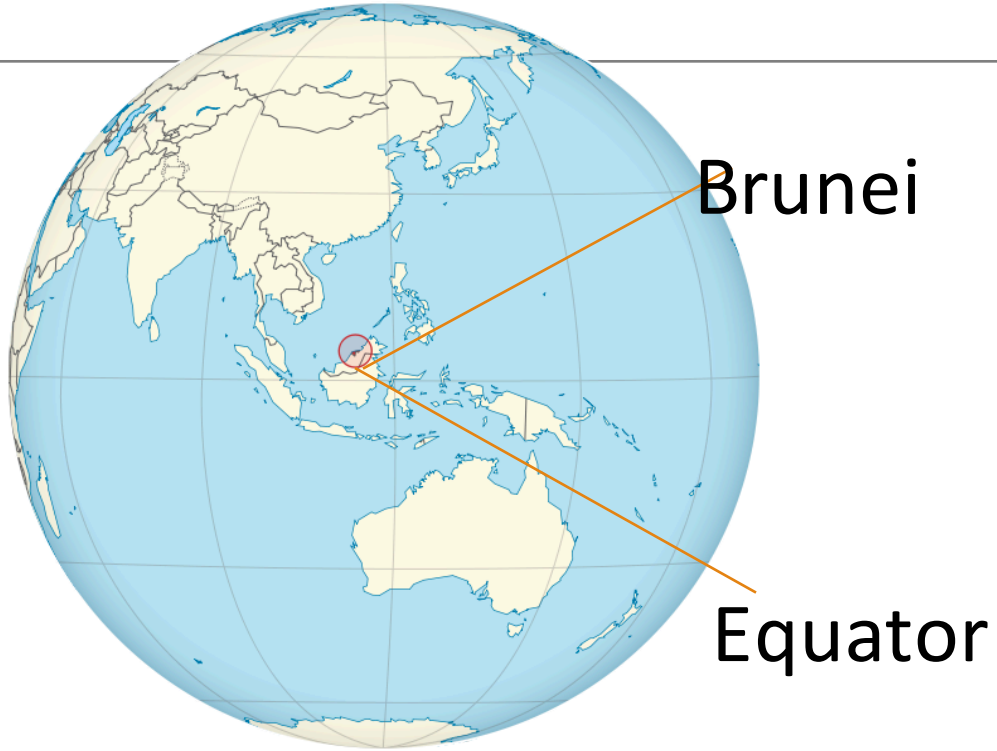
2000 2004 2009 2011 [2015]

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

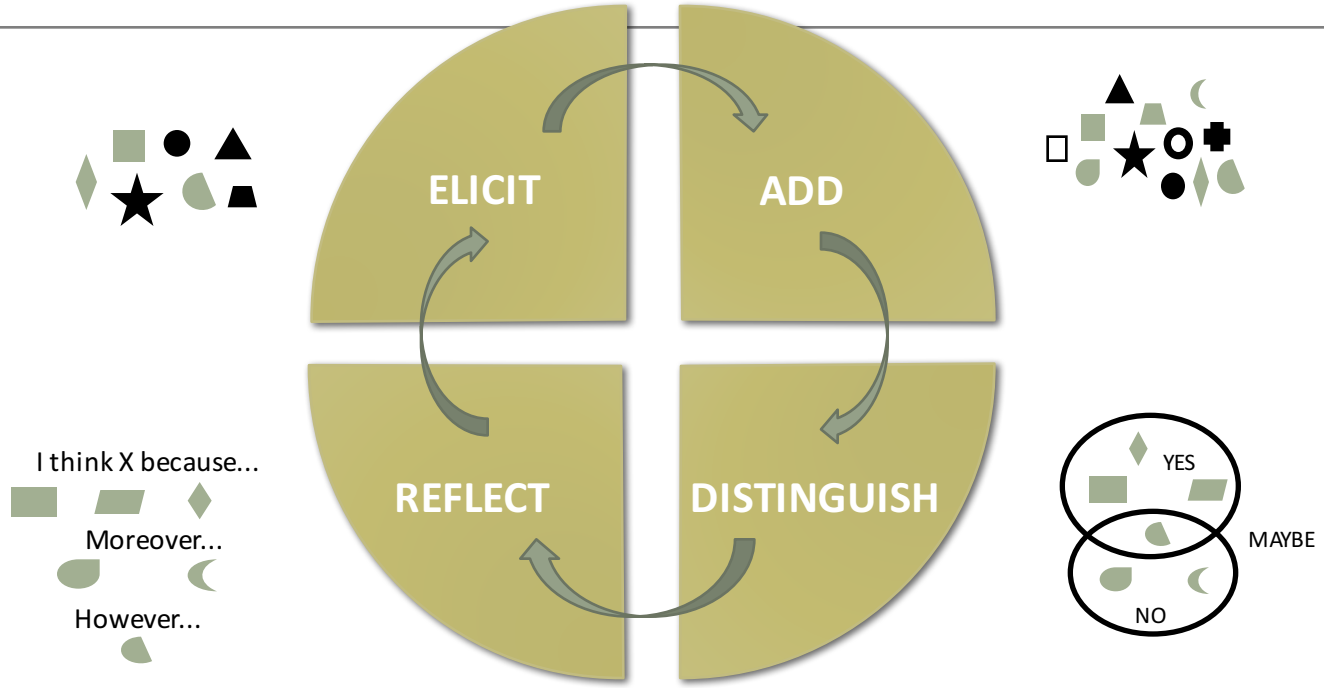


Talk to your neighbor

How do you elicit student ideas?

How do you build on them?

Knowledge Integration PATTERN



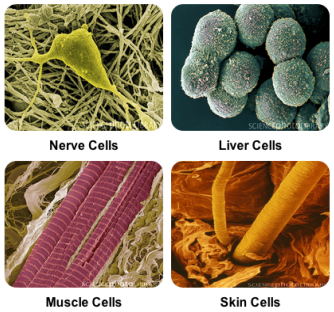
Donnelly KI Model, 2014; Linn & Eylon, 2011; Matuk KI Model, 2012;

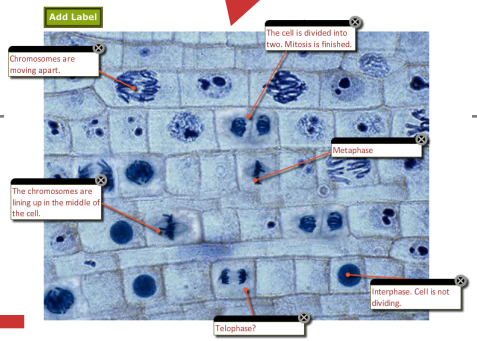
The *Mitosis* unit

Unit activity sequence

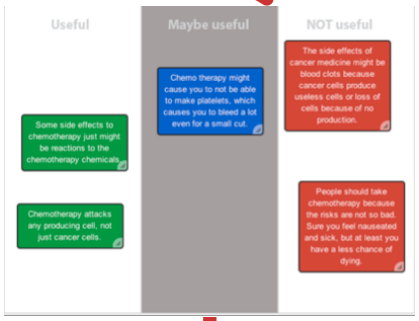
- What is cancer?
- Phases of cell division
- Trade offs, side effects
- Investigate 3 potential treatments
- Side effects of cancer treatment

ELICIT, ADD

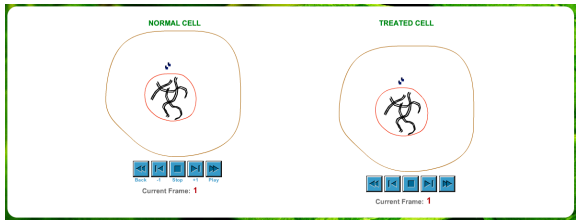




ORGANIZE



DISTINGUISH



REFLECT

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

We recommend Plant A because the medicine stopped the chromosomes from duplicating, and this would stop cell division.

SAVE RESPONSE Undo Changes

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

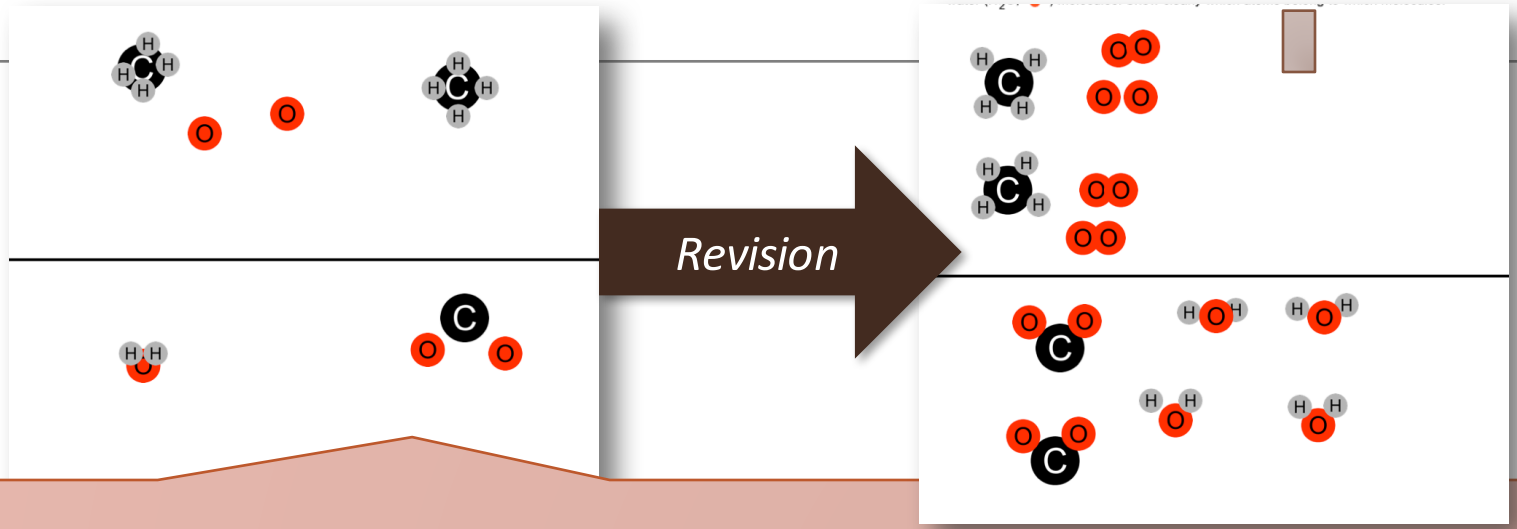
- We research design of optimal guidance for the response
- We explore branching students to alternative conditions

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

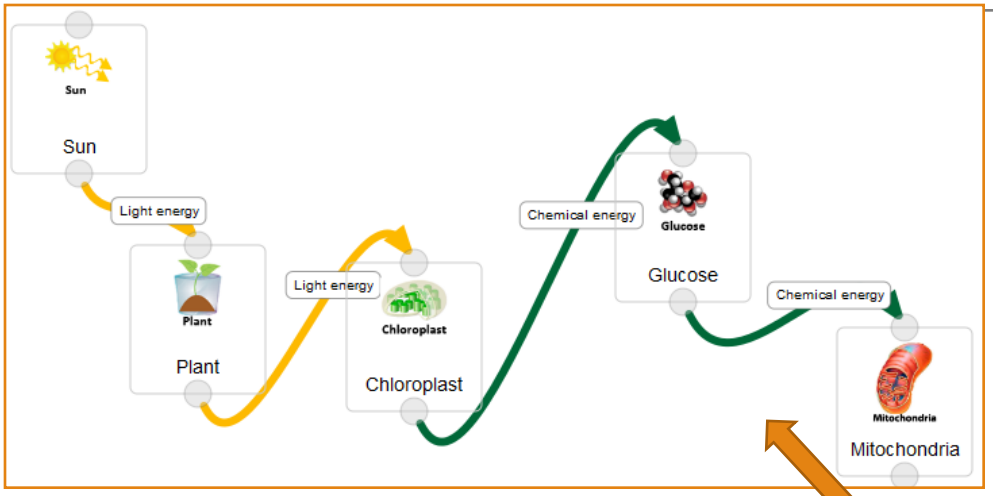
Automated Knowledge Integration Guidance



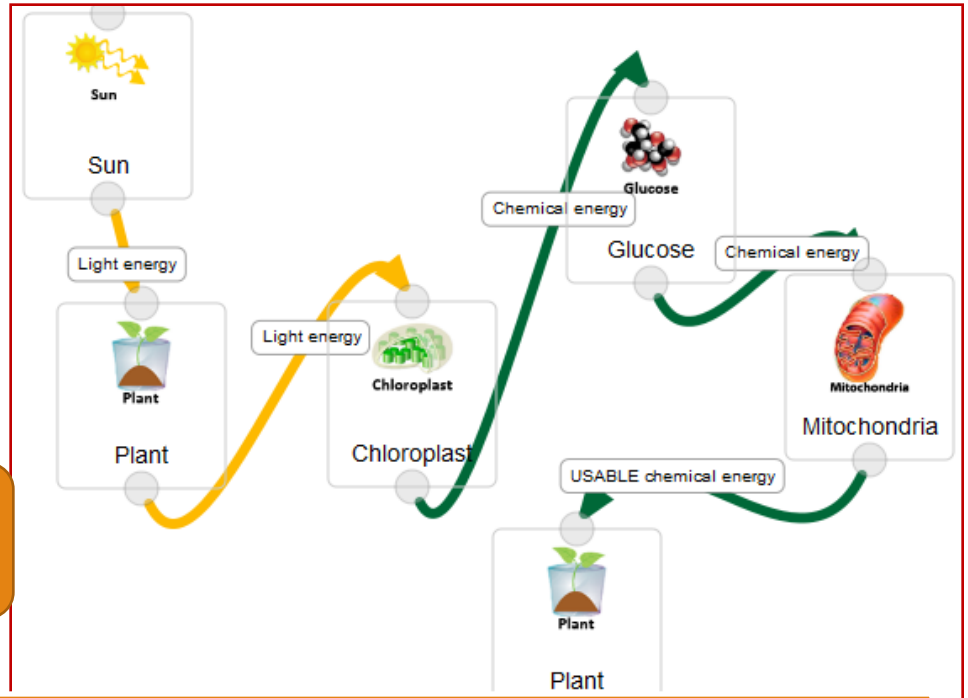
- Good start. You have correctly created 2 frames that represent the reactants and products of the methane combustion reaction.
- Can atoms in the reaction be spontaneously CREATED OR DESTROYED?
- Reread the directions and revisit steps 3.6-3.8. Make an improved drawing.

Rafferty, A., Gerard, L., McElhaney, K., Linn, MC. Automating Guidance for Students Chemistry Drawings." Proceedings of Formative Feedback in Interactive Learning Environments (AIED Workshop). 2013.

Analyze MySystem Concept Map
Automated Knowledge Integration Guidance



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



Linn, M. C., Gerard, L. F., Ryoo, K., McElhaney, K., & Rafferty, A. N. (2014). Computer-guided inquiry to Improve Science Learning. *Science, 344*, 155-156. doi: 10.1126/science.1245980

Analyze short essays
Explore best way to guide knowledge integration

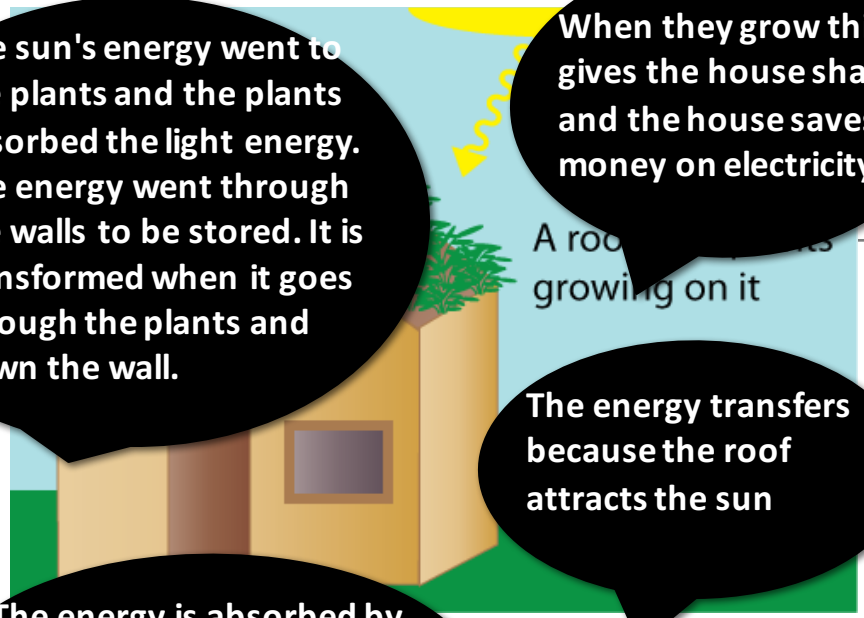
"I like when there is writing because with typing it feels like I can explain more instead of…just doing multiple choice, because then its kind of like I want to explain it really bad but you can only put an answer."

-- 7th grade study participant

Gerard, L & Linn, MC J Sci Teacher Educ (2016) 27: 111. doi:10.1007/s10972-016-9455-6

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.

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

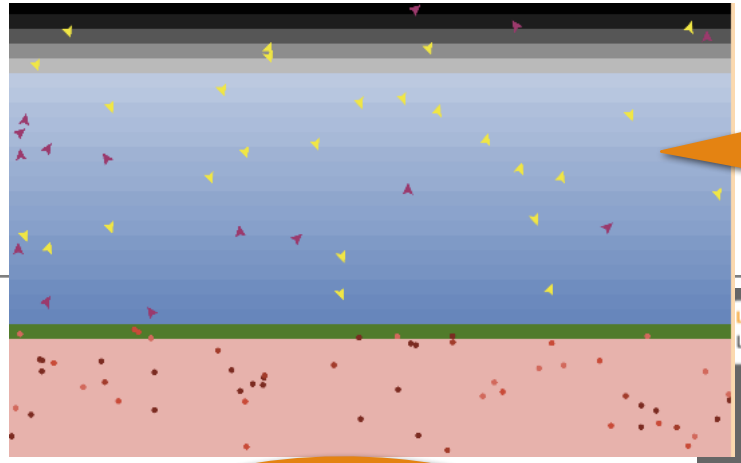
energy comes from pre-existing energy that transforms, energy is stored in molecules. Energy explodes and the chemicals inside change

The energy transfers because the roof attracts the sun

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

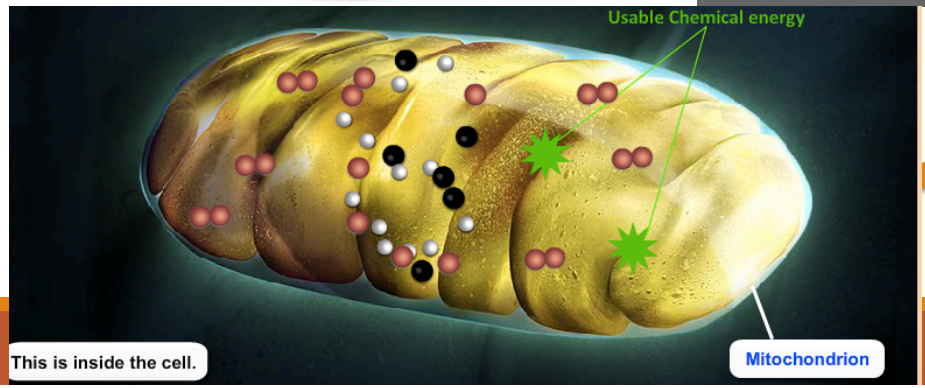
the energy is stored in the plant like solar panels and the plant can transform the energy to chemical for electricity

plants grow on the roof easier because they are more close to the light energy.



Where does energy come from?

How does energy change?



Why are plants important?

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

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

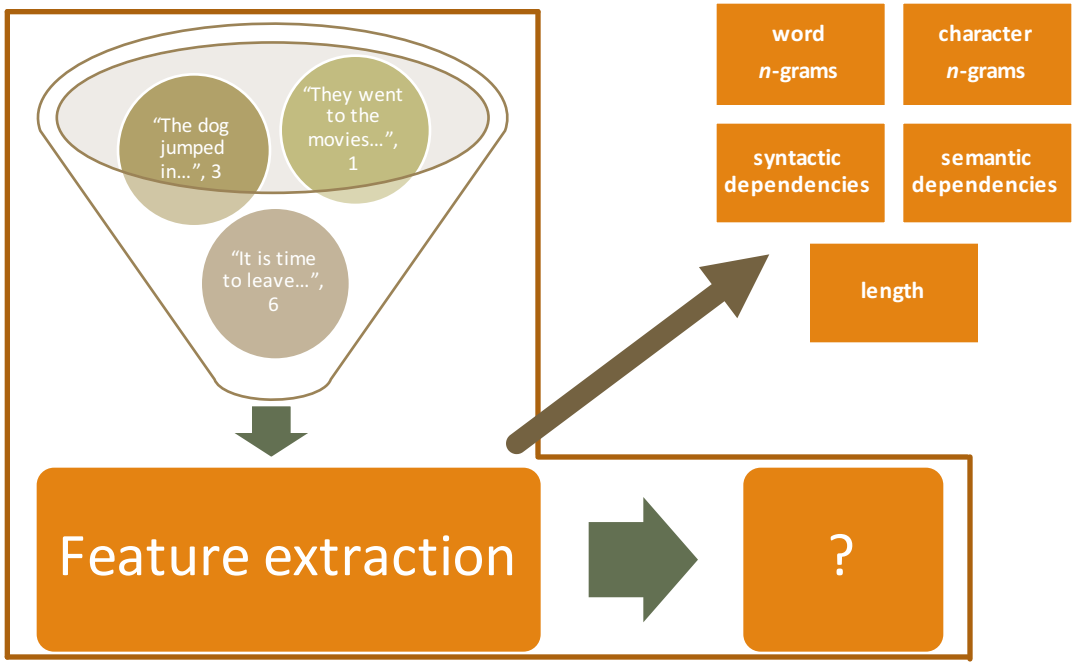
Liu, O. L., Lee, H.-S., Hofstetter, C., & Linn, M. C. (2008). Assessing Knowledge Integration in Science: Construct, Measures and Evidence. *Educational Assessment*, *13*(1), 33-55.

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

Liu, L., Rios, J., Heilman, M., Gerard, L., & Linn, M. (2016). Validation of automated scoring of science assessments. *Journal of Research in Science Teaching, 53(2),* 215-233

Model Building



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)

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!

Input Response

- "Hear, hear!"

character *n*-grams

- *n* = 2: {"He": 1, "ea": 2, "ar": 2, "r,": 1, ", ": 1, " h": 1, "he": 1, "r!": 1}
- *n* = 3: {"Hea": 1, "ear": 2, "ar,": 1, "r, ": 1, ", h": 1, " he": 1, "hea": 1, "ar!": 1}
- …
- *n* = 5: {"Hear,": 1, "ear, ": 1, "ar, h": 1, "r, he": 1, ", hea": 1, " hear": 1, "hear!": 1}

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

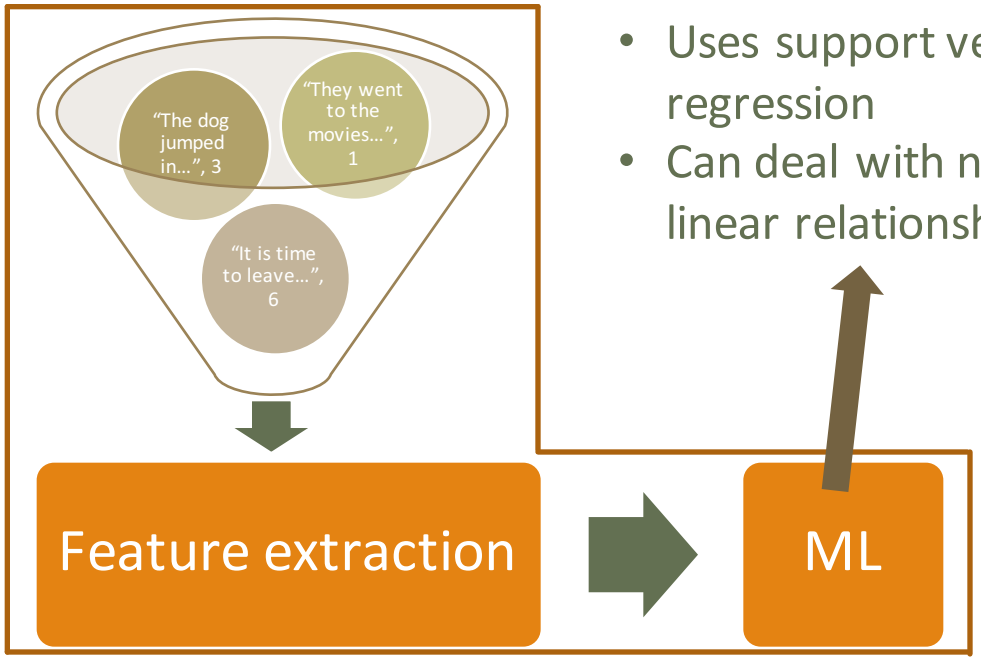
Length of response is determined by the log of the # of characters

$$log(chars)$$

chars

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

Model Building



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

Example Item Mitosis
Small sample size, kappa = .62

Automated (Columns)

Human (Rows)

	1	2	3	4	5	N
1	**22**	8	0	0	0	30
2	6	**131**	50	1	0	188
3	2	48	**89**	3	0	142
4	0	1	8	**6**	0	15
5	0	0	0	1	**1**	2
N	30	188	149	11	1	377

Liu, L., Rios, J., Heilman, M., Gerard, L., & Linn, M. (2016). Validation of automated scoring of science assessments. *Journal of Research in Science Teaching, 53(2),* 215-233

Example Item Simple Inheritance Larger sample and range, Kappa = .79

Automated (Columns)

Human (Rows)

	1	2	3	4	5	N
1	**9**	13	0	0	0	22
2	6	**310**	70	4	0	390
3	1	21	**131**	23	1	177
4	0	1	35	**56**	11	103
5	0	0	1	12	**7**	20
N	16	34	237	95	19	712

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

Liu, L., Rios, J., Heilman, M., Gerard, L., & Linn, M. (2016). Validation of automated scoring of science assessments. *Journal of Research in Science Teaching, 53(2),* 215-233

Will this still be powerful enough?

Example of Knowledge Integration Guidance Score = 2

Student Example	KI score	Knowledge Integration Guidance	Typical Teacher Guidance
the sun would go directly to it the rain would give it water and the chloroplast would take it in.	2 Non-normative; vague	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	Incorrect. Redo.

Most scores off by 1 at most, meaning that the guidance that is assigned is generally relevant.

Knowledge Integration Guidance Example, Score = 4

Student Example	KI score	Knowledge Integration Guidance	Typical Teacher Guidance
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.	4 One full scientific link between 2 ideas	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.	Add detail. Where do plants store energy?

Encountered an obstacle

Some students discounted computer guidance.
Added personalization and an explanation

Student Example	KI score	Auto KI Guidance 1
*the **sun would go directly to it**, the rain would give it water, **and the chloroplast would take it in**.*	2. Incomplete	**Jess and Owen**, expand your story. **How does the energy change inside the chloroplast?** Check out <**here**> for a hint. Then, revise your story below.

Patterns of responding to guidance
Added ideas, no revision

The energy from the light will only stay with the plant and will not transfer for your houses 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.

Integrated:
Predicts better future success than added

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 there 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.

Gerard, L. F., Ryoo, K., McElhaney, K. W., Liu, O. L., Rafferty, A. N., & Linn, M. C. (2015). Automated Guidance for Student Inquiry. *Journal of Educational Psychology*: doi:10.1037/edu0000052.

Linn, M. C., Gerard, L. F., Ryoo, K., McElhaney, K., & Rafferty, A. N. (2014). Computer-guided inquiry to Improve Science Learning. *Science, 344*, 155-156. doi: 10.1126/science.1245980

Meta-analysis Guidance Comparison			Meta-analysis Significant Moderators	
Automated Adaptive Guidance	Typical Instruction	p<.001	Prior knowledge	Low/medium benefits
Enhanced Adaptive Automated Guidance (such as Knowledge Integration)	Simple Adaptive Automated Guidance (such as specific hints)	p<.001	Prior knowledge	Low/medium benefits
			Design Features	Greater benefit for self-monitoring guidance & Generating activities

Gerard, L. F., Matuk, C. F., McElhaney, K. W., & Linn, M. C. (2015). Automated, Adaptive Guidance for K-12 Education. *Educational Research Review, 15*, 41-58. doi:10.1016/j.edurev.2015.04.001

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.

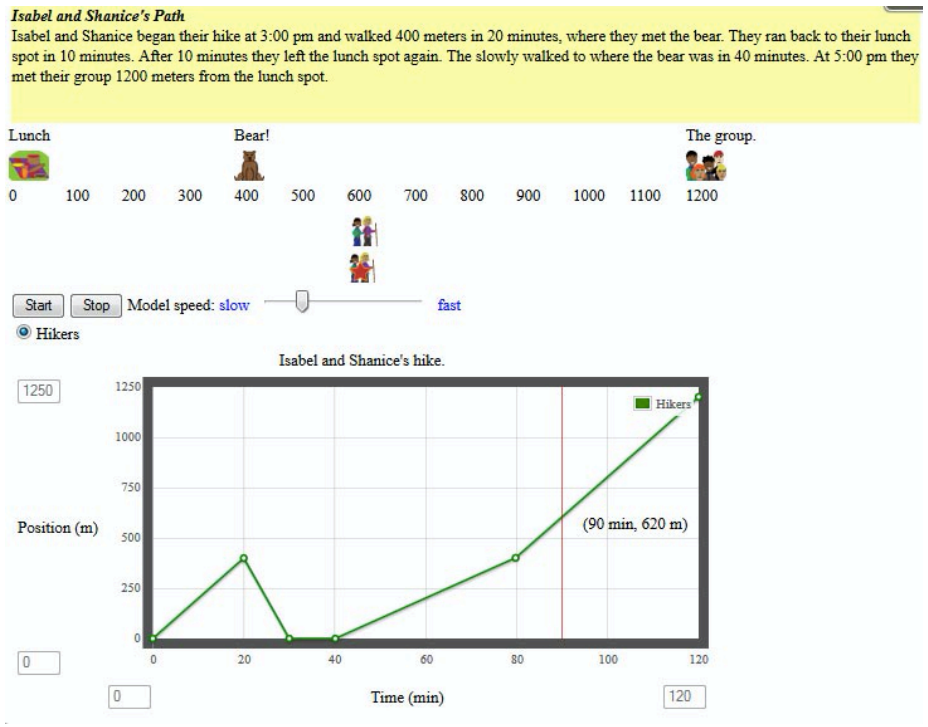
I don't know	Non-words	Off-task	Needs elaboration
i have no idea?	khnvvb	Stuff	they could be in different places.
i don't know sadly !!!	i hgfjdks	hi	The model will change.
idk	njhyfr68uvuh	I'm done	the natural selection leads like a boss.

Action:

Encourage refinement

Alert teacher

Guiding Student Interactions with Models and Graphs



Vitale, J. M., Lai, K., & Linn, M. C. (2015). Taking advantage of automated assessment of student-constructed graphs in science. *Journal of Research in Science Teaching.* doi: 10.1002/tea.21241

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 reviseideas 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?

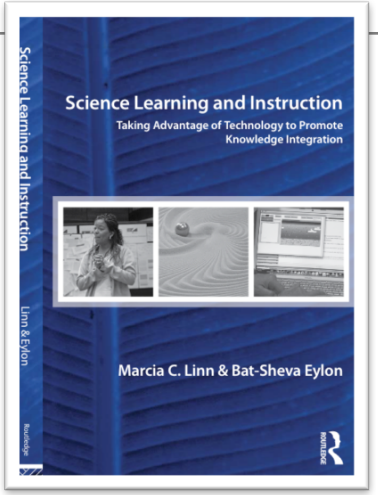
My Questions…….

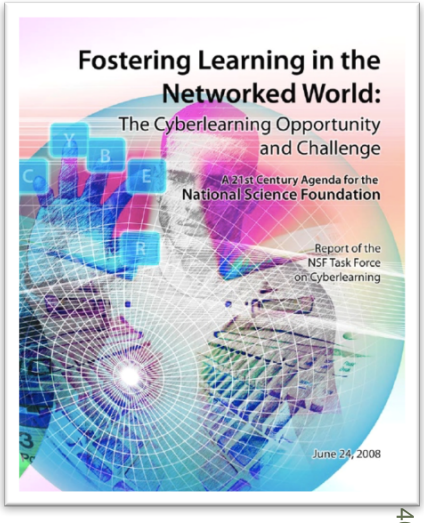
What are the implications of these findings for MOOCs, electronic textbooks, and LMS courses?

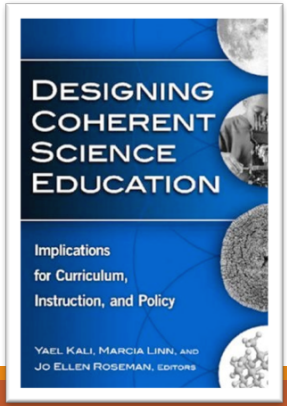
What are other ways to extend our support for inquiry learning?

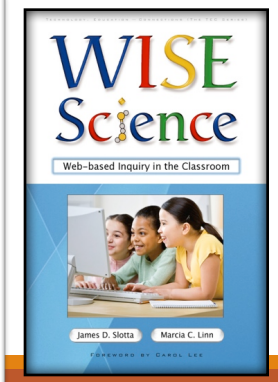
WISE is Free and Available

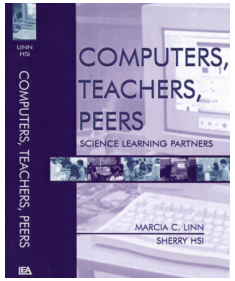
WISE.Berkeley.edu





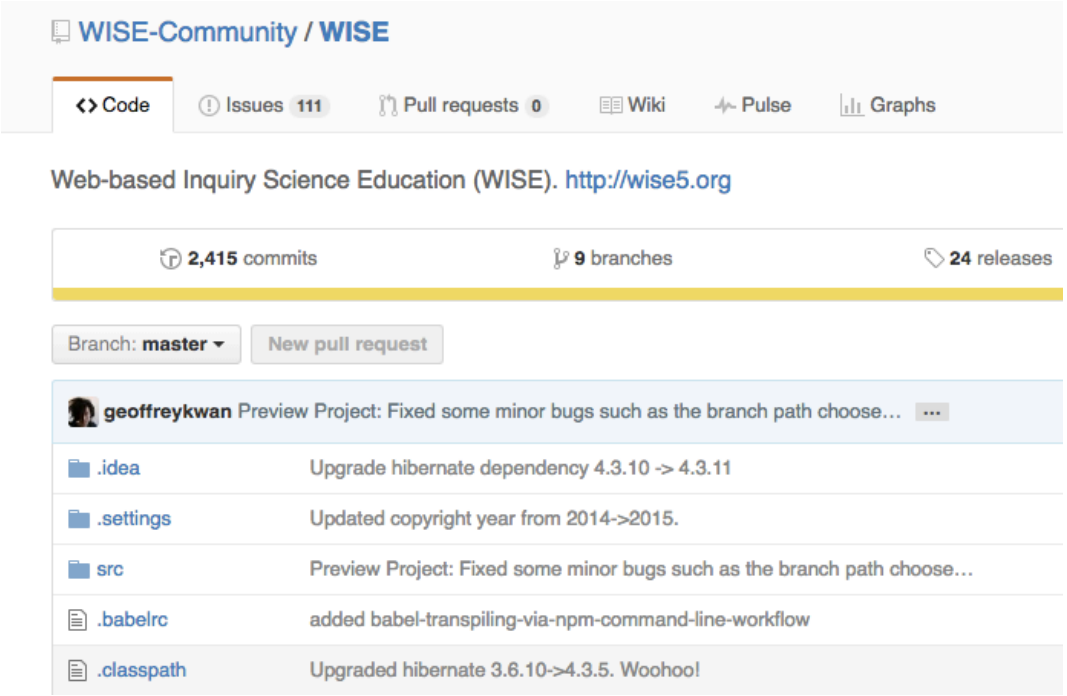




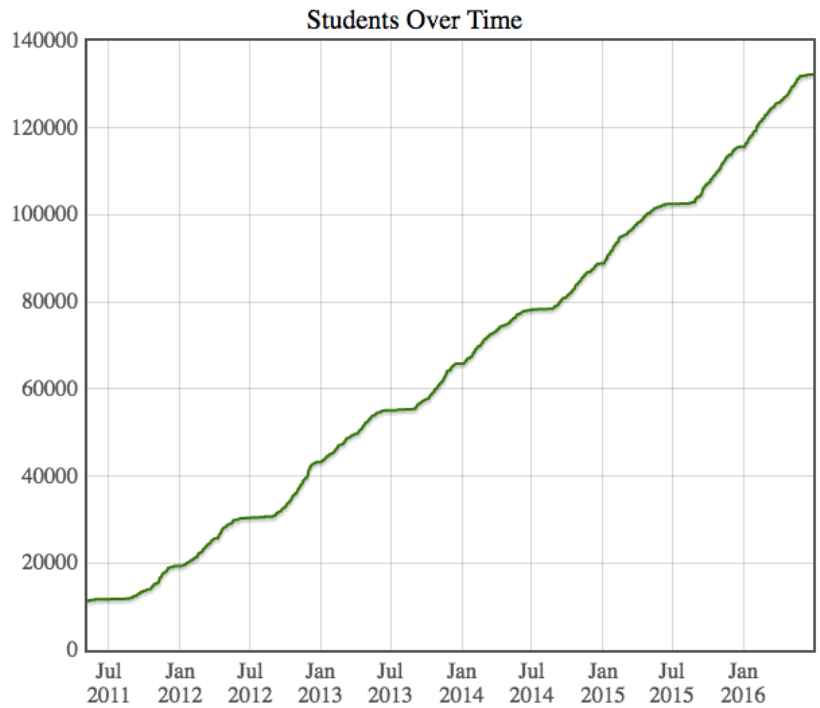


mclinn@berkeley.edu

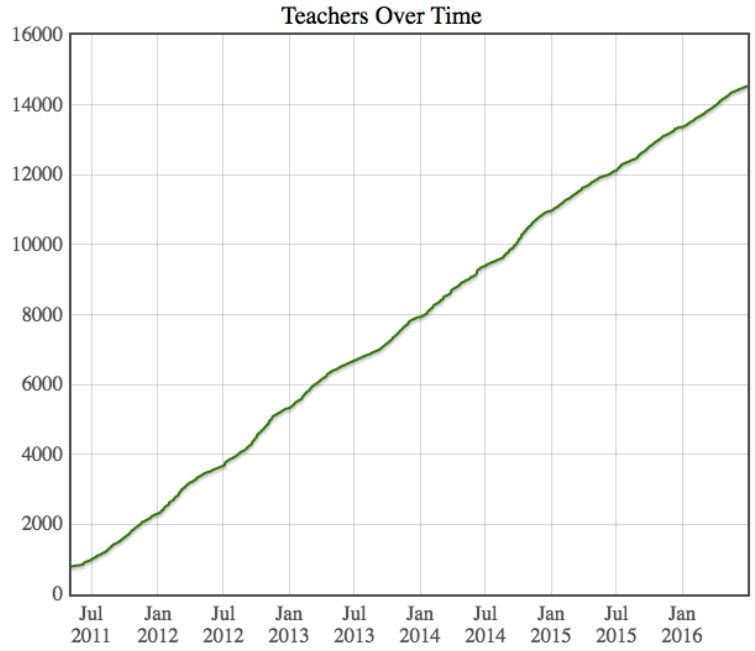
Join the WISE Developers Community https://github.com/WISE-Community/WISE



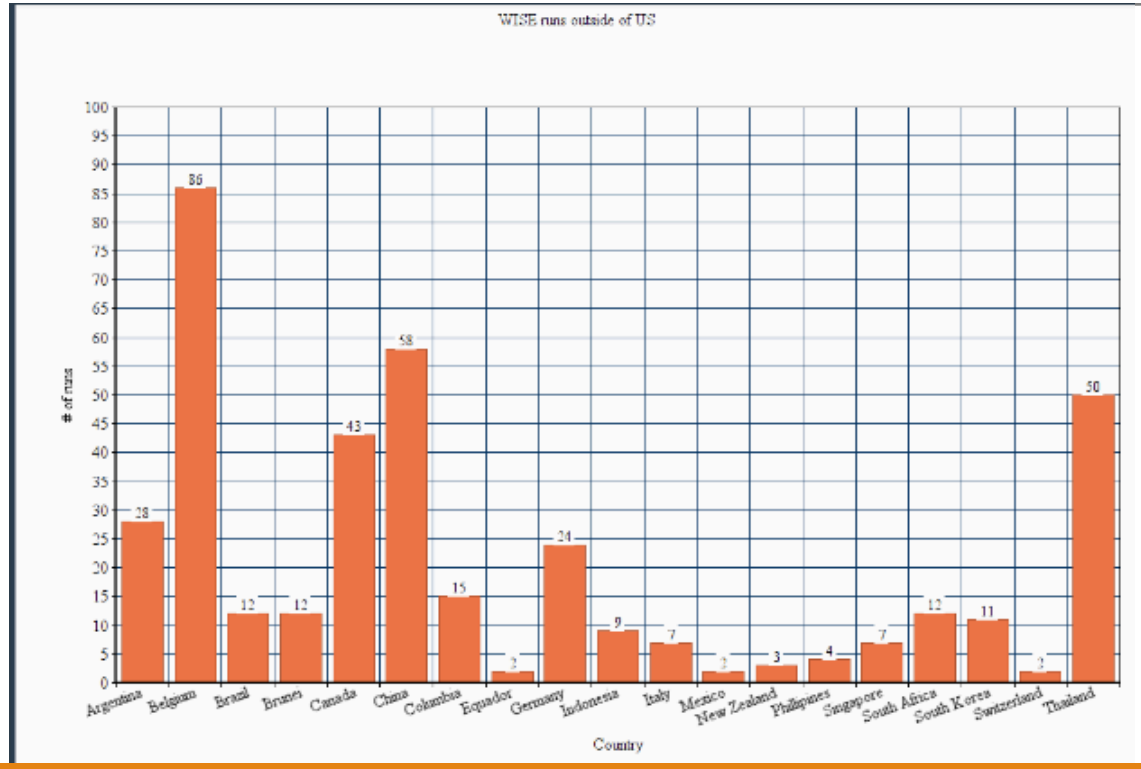
Many students use WISE



Many teachers use WISE



WISE use around the world
Servers in Taiwan, China, Argentina



Research groups in
Belgium
Canada
Germany
Thailand