Quantitative Insights on In-class Creation and Sharing of Knowledge

SLAM
Student Learning and Analytics at Michigan
January 30, 2015
Special thanks to...

- Caltech and PCC for iPads
- Helpful Dean/Vice Provost/Provost
- Interested faculty
- Willing students
- An awesome IRB
Today’s Outline

1. Background and Approach
   Data
   2. Participation Inventory
   3. Behavior in Time
   4. Modes of Learning
   5. Motivation and Outcome

6. Future and Conclusions

7. Supplemental: CSA Outreach
1. Background and Approach

- Context and Goals
- Research Questions
- Tablet-based Collaborative Learning App
- Classes & Kinds of Data
Improving learning & student engagement

Methods that work for students and faculty, and provide new evidence and insights.
SKIES, a collaborative learning application

Can we keep the same hypothesis set while changing the learning model? If so, give an example.

**Question**

How did you obtain the equation $X^T X w = X^T y$?

**Biofilms**

Biofilm - a very thin layer of microscopic organisms (such as bacteria) that adhere to a surface and grow in a layered structure covering the surface. An interesting fact is that these different layers of the biofilm have different environmental conditions. This results in the organisms living in a variety of conditions and states within a single biofilm! Very important concern for antibiotic resistance!

Flowers seen by humans (left) versus bees (right) because bees see in the ultraviolet, they can see extra markings which guide them to their target.

**Notes**

**Questions**

**Self-quizzes**

**Equations**

**Pictures**

**Web links**

**Videos**

Teachers and students add branches to a class tree.
Many elements ranging from the flexible to the authoritative.
Repair from a homologous chromosome

A allele serves as a template for repair. It keeps the cell from losing more DNA, but it also changes the original information.

Homologous recombination can create chromosomal instabilities

DNA with repetitive elements can become improperly modified as a result of homologous recombination. A linear chromosome with repeated sequences can end up looping back on itself, which upon recombination, can lead to excisions, inversions, and translocations.
Self-quizzes by students

Read about Dolly the sheep and whether she was "born old" in some ways.

Which cell does not have active telomerase activity?
- Stem cell
- Germ cell
- Somatic cell
- Cancer cell

Of the approximately two million follicles (immature eggs) that women have at birth how many end up actually maturing properly?
- 4
- 400
- 4000
- 40000
Discussions

Only considering the mutation involving chromosomes 6 and 15, what are the chances the offspring will be normal?

Question

- how many probes can a microarray hold and how are they made?

Answer

- Chips may hold from 10 probes up to 2 million depending on the application. Chips are created by machines that spot the DNA probes onto the glass surface.
What is Dolly’s age?
Germ cells (telomerase high)

somatic cells (udder cell from Dolly's clone mother/father)
(no telomerase)

Telomere length

Dolly

immortal cells (telomerase on)

senescence

Cell divisions

Crisis

Telomere length of cells in Dolly?

- Comparable to that of a six year older control (sheep live to be about 12 normally)  Nature 399:316-317

Q/A: What is another way Dolly's genetic material was likely different from that of...
Hydrogen as a fuel

Hydrogen plus oxygen combines to form water in an exothermic process:

\[ H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad E = 1.23\text{V} \]

Since two electrons are involved in this reaction, there is a net production of 2.46 eV per molecule of water made.

Why does higher voltage make it less favorable to generate \( O_2 \), but more favorable to generate \( H_2 \)?

Solar needs to be coupled to energy storage

Because people like to work before sunrise and after sunset, there will be periods where there isn’t enough sunlight available to provide energy. Thus we need a way to store solar energy for later.

Pourbaix diagram

Hydrogen may be an ideal energy storage device

\[ 2H^+ + 2e^- \rightarrow H_2 \quad E^\circ = 0 \]
\[ 2H^+ + 2e^- + \frac{1}{2}O_2 \rightarrow H_2O \quad E^\circ = 1.23\text{V} \]
\[ H_2 + \frac{1}{2}O_2 \rightarrow H_2O \quad E^\circ = 1.23\text{V} \]

Using the Nerst equations derived previously, we can plot out the regions where \( O_2 \) and \( H_2 \) are spontaneously generated, as a function of applied voltage and pH.

Coupling light to fuel production

When \( Ru^{2+} \) is excited by light, it becomes an active species which can either donate or accept an electron to become lower in energy. The electron can then hop back on/off to recreate \( Ru^{2+} \).

We can couple this oxidation/reduction to the electrolysis half-reactions. The 0.87 V reduction potential is strong enough to produce \( H_2 \), but the 0.82 V oxidation potential is too weak to produce \( O_2 \).
Card ratings
Qualitative data from surveys

How and why do you think SKIES was useful to your learning?
How could SKIES have been more helpful to your learning?
How was your experience using SKIES for this class different from when using other learning tools like laptops, note-taking programs, or browser-based browsers?

Motivation
Usage
Efficacy

Access to helpful material from students/TAs
Improved studying
My own enhanced learning
A sense of contributing to the class
Other motivation:
Other motivation:
Answer questions about classroom active learning

How do students choose to participate?

How can we quantify in-class engagement?

What motivates students? Faculty?

App provides a durable record of learning in the classroom
Research Questions

• What are the observable patterns of real-time student engagement during class, under open (student choice) and directed conditions, for individual students and group behaviors?

• What types and levels of complexity are present in student engagement during class, both self-reported and independently observed?

• What relationships exist between student engagement, student learning, student motivation, and faculty experience adopting active learning methods?
Administrative and technology logistics

Research & coordination

Programming & teaching support

100 iPads

Provost’s Innovation in Education Fund (Caltech), Bechtel Foundation (Caltech), CTE Funding (PCC)

Caltech

Genetics

Chemistry

+ 3 others

Pasadena City College

Calculus

+ 6 others

This talk: two classes at Caltech and one at Pasadena City College
Degree of structure & change to existing instruction

- Low: 35 students
  - Genetics

- Medium: 53 students
  - Chemistry

- High: 45 students
  - Calculus
**Question**

why would the other d orbitals not get destabilized in a tetrahedral structure (esp the x2-y2 one)

**Teacher** — 1 week ago

Which levels would be destabilized if the ligands bound in tetrahedral fashion?

?  

**Teacher** — 1 week ago

Ligands at octahedral positions destabilize the $d_{x^2}$ and $d_{x^2-y^2}$ orbitals, breaking the degeneracy of d orbitals in the free atom.

**Teacher** — 1 week ago

Normally the d orbitals of Ru have the same energy (are degenerate).

However, when the bpy ligands bind, they do so in an octahedral fashion, e.g. along the x, y, and z axes. This causes the energy of the $d_{x^2-y^2}$ and $d_{z^2}$ orbitals to be pushed upward. The 6 electrons of Ru$^{3+}$ end up occupying the $d_{xy}$, $d_{yz}$, and $d_{xz}$ orbitals.

**Energy Splitting due to d-orbital Interference**

The molecule has so many electrons near each other that the electron orbitals interact with each other and change their energies. d-electrons all fall into xy, xz, and yz orbitals (the lower energy d-orbitals).

**Student** — 1 week ago

What is it called if the electron is forced down to lower energy photons?

**Teacher** — 1 week ago

Electronic excitation

Light of 400 nm can excite the metal to the π* orbital of bpy.

The splitting between d orbitals is the reason that the π* orbital energy is lower than that of the d orbitals.
What does the integral look like after substituting u and du?

Question

Definite Integrals - now we lose the constant, C.

\[ f(x) = 2x + 4 \]

\[ \int_{1}^{2} (2x + 4) \, dx = F(2) - F(1) \]

\[ \int_{-1}^{1} (2x + 4) \, dx = F(1) - F(-1) \]

Student — 11 months ago

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2. Participation Inventory

- Counting Cards
- Self report vs. App data
- Student, TA, and Faculty contributions
Counting cards
Student self-reported use of SKIES

- View the professor's course material: Often
- Move forward, backward, or zoom in/out on material: Often
- View material contributed by students/TAs: Sometimes
- Add quiz questions and/or flashcards: Occasionally
- Add notes (e.g., clarifications, definitions, explanations): Occasionally
- Ask questions for others to answer: Occasionally
In genetics, how many cards were added?

<table>
<thead>
<tr>
<th>Slides for 14 lectures</th>
<th>834</th>
</tr>
</thead>
<tbody>
<tr>
<td>Added year 1</td>
<td>843</td>
</tr>
<tr>
<td>+ added year 2</td>
<td>1036</td>
</tr>
<tr>
<td>= Total added</td>
<td>1879</td>
</tr>
</tbody>
</table>

>2.2 additions, quiz questions, papers etc. per slide
In genetics, who makes cards?

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAs</td>
<td>696</td>
<td>430</td>
</tr>
<tr>
<td>Students</td>
<td>147</td>
<td>606</td>
</tr>
<tr>
<td>Total</td>
<td>843</td>
<td>1063</td>
</tr>
</tbody>
</table>

Students contributed more cards than TAs by Year 2
Class structure affects student participation

Students add many cards in the low and high structure extremes
In the low structure class, a few students add most of the cards.
In the high structure class, many students add a few cards.
Contributions from teaching assistants

TAs were particularly active in the medium structure class
Student participation: Conclusions

The most participation came from classes with **low** or **high** degrees of structured tablet use.

In the **low** structure case, a subset of students became very active teachers/contributors.

In the **high** structure case, a broader range of students contributed more uniformly.
3. Behavior in Time

- In-class time lapse
- Learning Curve
- Waiting Time
Mutations and cancer
10^{10} cell divisions DNA replication events/site.
The mutation rate per nucleotide/DNA replication event is 10^{-7}.
Every single nucleotide mutation occurs in our genome hundreds of times each day.
Mitotic recombination can convert heterogeneous cells into homogeneous. Rates range from 10^{-7} to 10^{-10} per individual generation.

If the mutation rate per nucleotide is 10^{-7}, why are there so many mutation events in our body every day?

Genetic Alterations in Cancer
- Mutations
- Deletions
- Amplifications
- Translocations
- Rearrangements
- Epigenetic Events (Methylation)

Spontaneous
- Induced
- Chemicals
- Ionizing radiation
- Environmental factors
- Hereditary factors
- Translocations
- Rearrangements
- Mutations
- Additions
- Deletions
- Repeats

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Card creation over time: IC1 Genetics

Students + TAs make cards steadily over the term
After an initial learning curve, rises to a steady-state 44 cards/hr.
Card creation by a “model student”

Exponential distribution if inspired to create at a constant rate
Individuals are not model students though

<table>
<thead>
<tr>
<th>waiting times</th>
<th>seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>student #1</td>
<td></td>
</tr>
<tr>
<td>student #2</td>
<td></td>
</tr>
<tr>
<td>teaching</td>
<td></td>
</tr>
</tbody>
</table>

Creation rate observed to flag right after making a card
Collectively, though, the class acts as a model student

Taken together, the class is attentive and creating constantly
Engagement versus time

**Principle of collaborative learning**

Sharing combines attention spans, to everyone’s benefit

Palm-Khintchine theorem; superposition of non-Poisson processes
Attention span ebbs and flows add up: collectively, class may behave like an “ideal student.”

This may shift instructional views of “engagement”: the class may be engaged, just not all equally at the same time.
4. Modes of Learning

• Types of Contributions
• Cognitive Complexity of Contributions
• Complementarity and Knock-on Effect
• Wait Time for Different Complexities

Detailed analysis of Genetics
What kinds of cards are made?

<table>
<thead>
<tr>
<th></th>
<th>information</th>
<th>assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAs</td>
<td>497</td>
<td>629</td>
</tr>
<tr>
<td>Students</td>
<td>645</td>
<td>108</td>
</tr>
<tr>
<td>Total</td>
<td>1142</td>
<td>737</td>
</tr>
</tbody>
</table>

TAs like to make questions; students like to make notes.
How many words are in each card?

TAs are more verbose than students (~32 vs 20 words per card)
# Genetics Coded Card Set
838 Cards, Lectures 1 thru 8 (out of 14)

<table>
<thead>
<tr>
<th>Code</th>
<th>Type</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-F</td>
<td>Note—Fact</td>
<td>Definitions, terms, short factual materials</td>
</tr>
<tr>
<td>N-S</td>
<td>Note—Summary, Synthesis</td>
<td>Boiling down, bringing together, connecting material</td>
</tr>
<tr>
<td>N-I</td>
<td>Note—Insight</td>
<td>Elaborating, clarifying, interpreting, concluding</td>
</tr>
<tr>
<td>Q-R</td>
<td>Question—Recall</td>
<td>Self/peer quiz asking simple facts, definitions, information</td>
</tr>
<tr>
<td>Q-T</td>
<td>Question—Thinking</td>
<td>Self/peer quiz asking complex question requiring thought</td>
</tr>
<tr>
<td>Q-O</td>
<td>Question—Other</td>
<td>Open-ended questions, answers to other students’ questions</td>
</tr>
<tr>
<td>O</td>
<td>Other</td>
<td>Supplemental and related material from outside sources; “Human Interest” tangents, stories, humor, etc.</td>
</tr>
</tbody>
</table>
Who made cards in the coded set?

Coded cards were made by students & TAs in the same proportion as all genetics class cards.
Inter-rater Reliability

- Twice-coded 1/3 of coded set

- Cohen’s Kappa = 0.53 (moderate)
- Pearson’s r = 0.92; 0.99 for within-category
How do students actively engage in card-making?

Student Cards

Students lean toward notes and facts.
How does TA card-making differ?

TAs add more complex notes and substantially more questions.
Overall, how does the student/TA collaboration look?

Students and TAs together create a varied set of learning resources.
Some cards take longer to make than others

Shorter wait times associated with question type cards
occurrences

wait time prior to card creation | seconds
Complexity and Modes of Engagement

Students and TA contributions differ in type and cognitive complexity.

It takes students longer to do more complex tasks.

The overall result is rich and complementary.

“Knock-on effect” of increasing overall engagement.
Consider & Contribute:

How does classroom teaching change when it is visibly collaborative?
5. Motivation and Outcomes

- Student motivation
- Faculty self-report
- Student learning
- Student self-report
Encouragement and in-class rewards

“Reading is a good way to learn; teaching is a great way to learn. We encourage everyone to contribute flashcards to the class tree (and any other kind of card as well).

Top contributors will be recognized at the end of each lecture.”

– e-mail to students

Various incentives provided to encourage participation
Why do students report using SKIES?

Self-reported as most important
1. Access to helpful material from students/TAs
2. My own enhanced learning
3. Improved studying
4. Making class time more engaging
5. Enhancing my ability to focus

Self-reported as least important:
6. Having my questions answered
7. A sense of contributing to the class
8. In-class rewards
9. Recognition by the professor
10. A sense of competition with others

Students say intrinsic motivations are most important
Faculty outcomes (self-reported)

SKIES was a great benefit to my class... This activity by the students may have helped to draw people out a bit since it provided a forum in which to shape the class and participate rather than just sit and absorb.

One other thing about this class that made it remarkable was the number of questions the students asked. Sometimes it was difficult to make it through the lectures, there was so much querying going on. SKIES is likely to be a part of it, allowing students to quickly go back through the slides and links.

SKIES also helps in a more general way in that it provides a way to get them... comfortable in the idea that they are a part of creating [the class]. This then makes them generally more engaged & inquisitive.
The one other data point we have is just how well the students did overall. Here I am a bit embarrassed and shocked. The average grade this year was astonishingly higher than in all previous years I have taught the course. It really was quite a change.

Usually this is considered one of the hardest required courses because it focuses on tricky problem solving. It normally serves as a bit of a weed out course.
Average GPA (learning) jumped with SKIES

Problem sets, exams + extra credit problems to boost score

2009 Ave = 85

2010 Ave = 88

2011 Ave = 86
Average GPA (learning) jumped with SKIES

*Problem sets, exams + extra credit problems to boost score*

2009 Ave = 85

2010 Ave = 88

2011 Ave = 86

+SKIES 2012 Ave = 98.2
Average GPA (learning) jumped with SKIES

Problem sets, exams + \textit{extra credit}
\textit{problems to boost score}

2009 Ave = 85

2010 Ave = 88

2011 Ave = 86

+SKIES 2012 Ave = 98.2

+SKIES 2013 Ave = 89.6  Extra credit eliminated
Self-reports of how SKIES helped learning

SKIES was very engaging and allowed me to remain more focused in class.

SKIES was very helpful for supplementing the lecture slides. Often, it is difficult to pick up on what material is being presented in the slides, and the cards were very helpful for figuring out what material we learned.

Interactiveness helped a lot. Made it fun.

It was helpful to be able to manipulate the notes during lecture, I could go back and check things.

Writing things/typing things down is a good way of repetition of material, especially material heard audibly. It strengthens learning in that manner.
Conclusions

- SKIES-based active and engaged learning benefits student learning and faculty teaching practices.

- Actionable analytics emerge from real-time student behavior available as a result of SKIES.

- Benefits are evident across a range of use cases; SKIES is a gateway drug for teaching transformation.
6. Conclusions and Future Directions

Now under investigation

- Self-efficacy with respect to technology, content, general student experience.

- Role of teaching assistants in changing teaching practices.

- Role of immediate access to learning analytics: Faculty, TAs, Students.

- Synthesis of learning analytics data: e.g., weekly engagement report with recommendations.
Spread at Caltech: 3 classes in Year 1 (2012)

- Genetics
  Bi 122

- Computational chemistry
  Ch 121

- Theoretical chemistry
  Ch 120
Spread at Caltech: 5 classes in Year 2 (2013)

Genetics
Bi 122

Computational chemistry
Ch 121

Theoretical chemistry
Ch 120

Machine learning
In-class part of flipped MOOC
(>200,000 students)
CS 156

Solar lab chemistry
Ch 3X
Proposed at Caltech: 9 classes in Year 3 (2014)

- Genetics: Bi 122
- Computational chemistry: Ch 121
- Theoretical chemistry: Ch 120
- Machine learning: CS 156
- Solar lab chemistry: Ch 3X
- Freshman lab chemistry: Ch 3A
- Digital ventures: EE 150
- Orgo/Physical chemistry: Ch 1
- Inorganic chemistry: Ch 102
The next step

Interlinking Caltech courses across levels & disciplines

Connecting it all into a large-scale knowledge graph
A GPS for learning

Traverse real or virtual classrooms on the way to goals & aspirations

What you **know**
What you **don’t know**
What you **want to know**

Algorithm patent US 8,832,117
Democratizing teaching, research, and exploration

... to achieve an impact far disproportionate to our size.
6. Conclusions and Future Directions

**Ultimate objectives**

- Break down silos, interlinking material across core classes; and ultimately between universities, schools, and other organizations.

- Use detailed engagement and micro-assessment data on a global knowledge graph to create personalized learning paths.

- Learning paths guide students through classes and online resources to distant learning goals and aspirations.