Using clickers to maximize and measure student learning in biology

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Scientific Teaching:
If we approach teaching the same way we approach scientific research, we can make informed decisions about how to improve student learning.
(Handelsman et al, 2004)

Not a new idea: educators have been thinking about this, primarily for K-12 students, for decades

What is new:
Extending these studies to college and medical school students
Involvement of national scientific associations
  AAAS "Science for All Americans", "Vision and Change"
  National Research Council (e.g. Bio2010, How People Learn)
  National Academy of Sciences, HHMI (sponsored institutes)
There is overwhelming evidence that engaging students actively in the learning process produces better outcomes.

PRIOR KNOWLEDGE

↓

DISSONANCE

↓

CONSTRUCTION OF NEW KNOWLEDGE

How People Learn, NRC; Ausubel, 1978

With straight transmission of information, students don’t learn to transfer knowledge to novel situations, and don’t develop good reasoning skills.
Maximizing student learning in the classroom:

Active techniques give students the opportunity to:
- solve problems in class
- measure their progress
- discuss ideas with each other

There are many ways to study the effects of changing pedagogy on student learning

One approach is to look at evidence of learning in the classroom
Frequent testing = better retention
(Kornell et al. 2009, Karpicke and Roediger, 2008)

Holds true even when students are not getting the “test” questions correct, and is amplified by feedback

Clicker questions can be used to promote student learning in the classroom

Clickers: a technology that allows for immediate feedback
Clicker question cycle:

1. Use questions that address key components of learning goals

2. Ask question in class (individual vote)

3. Students discuss ideas with each other (peer discussion)

4. Re-vote

5. Explanation of correct/incorrect answers

Subtleties:
- Instructor-centered: I explain the answer to you after you vote
- Student-centered: I let you discuss the answer and revote
Imagine that earlobe attachment is dictated by a single gene (a simplification), yielding two traits: unattached and attached.

Unattached earlobes are due to the dominant allele (top picture)
Attached earlobes are due to the recessive allele (bottom picture)

From this information, you can conclude:

a. Attached earlobes are seen less frequently than unattached earlobes in a population
b. Attached earlobes are seen more frequently than unattached earlobes in a population
c. Either phenotype could be seen more frequently in a population: you need more information
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This increase in % correct after discussion has been seen by many educators.

...but are students just copying their “knowledgeable” neighbor rather than actually learning from the discussion?
If students learn from peer discussion, they should show better performance on a similar question.

After discussion and revote on Q1, ask a second, similar question without any instructor input: Q2.
Each student answers anonymously while in class, but the clicker software keeps track

1 2 3 4 5...
student A: C B A D B...
student B: B B A A B
student C: B B A D B
student D: B C A A B

Answers can then be tabulated as correct or incorrect by student, by class period, by topic, etc.
Testing the value of peer discussion:

Students answer a clicker question individually (Q1).

Students talk to neighbors and answer Q1 again (Q1<sub>AD</sub> for Q1 “After Discussion”).

Students answer a different question individually (Q2). Q2 is asking about the same concept as Q1 (isomorphic).

The histograms of student responses are not displayed until after all questions answered.

n = 350 students (Genetics)
16 sets of questions

Can we distinguish between two possible ways that students are interacting?

**Transmissionist view**: the stronger students explain the correct reasoning to the weaker students, who therefore now understand it.

**Constructivist view**: in the process of actively discussing and defending different points of view, students arrive at a correct understanding by themselves.
Yes: even when questions are initially difficult, students can answer correctly after discussion

Very few students knew correct answer to Q1, but after discussion, many more answer correctly: students are constructing their own knowledge

Professors like to talk... does this research mean we shouldn’t? (peer discussion is enough?)
Compare peer discussion to instructor explanation, and to a combination of both (in two different genetics courses)

Our hypothesis: peer discussion followed by instructor feedback will produce the highest learning

The combination mode does results in the highest increase in learning (normalized change, \(<c>\))

\[ \frac{100(\text{mean Q2}-\text{mean Q1})}{(100-\text{mean Q1})} \] for each student for each question; then averaged

*Non majors show less improvement on many measures of learning than majors: Knight and Smith 2010
Which students are most helped by the combination mode?

Students classified by overall performance on clicker questions
Weak: <33% correct; Medium: 33-66% correct; Strong: >66% correct

Combination is better for all students

Instructor explanation is particular un-helpful for strong students
Student comments suggest they see the value of working on clicker questions

“When I was thinking about a problem later on I could think back and say, ‘oh yeah, like the clicker question in class.’ If I remembered getting a question wrong it would definitely motivate me to look up the answer and see why I wasn't understanding it.”

“I was really disappointed if I got a review clicker question wrong because we had gone over the answer before. It meant that I obviously needed to read the question more carefully or learn that idea.”

Students clearly benefit from peer discussion in class. But what are they actually saying to each other?
What makes for a productive discussion, in which students work together to create understanding?

**Developmental Biology**

One of three possible required “capstone” courses taken by juniors and seniors

Students have taken Introductory Biology, Genetics, Cell Biology, Molecular Biology, Chemistry, Biochemistry, Physics...etc

Students sit together around tables, solve problems as a group, and are frequently asked to answer and discuss clicker questions
Question cycle: Q1 individual → peer discussion → Q1ad (no Q2)

Record conversations of students in four different groups throughout the semester, during peer discussion (between Q1 and Q1ad)

83 different conversations were transcribed for 34 different clicker questions
Characterization of clicker questions over one semester of Developmental Biology

# students in class: 107, avg response rate, ~ 95%
How are students discussing their answers?

3 dimensions of coding

• Reasoning (offering either justification for their ideas, using evidence, or making sense of an idea by restating in own words)

• Participation (turns of talk, dominance)

• Social
  • How students challenge or support each other
  • What kinds of questions they ask each other

Each student utterance is coded for all three of these dimensions; coding is summed and averaged per conversation
Students mostly engage in constructivist conversations (in which multiple students offer reasons for their answers) more than students in Intro Astronomy (James and Willoughby 2011).
What characterizes a productive conversation?

**Process:** students are working towards understanding the content and concepts
- more than 1 reasoning statement (at least 10% of conversation devoted to reasoning)

**Outcome:** students answer correctly
- 70% or more of students answer correctly on revote
Most clicker discussions are both process and outcome productive

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Both Process and Outcome (reasoning and correct answer)</td>
<td>57/83 (65%)</td>
</tr>
<tr>
<td>Process only (reasoning, but not correct answer)</td>
<td>20/83 (24%)</td>
</tr>
<tr>
<td>Outcome only (no reasoning, but correct answer):</td>
<td>4/83 (5%)</td>
</tr>
<tr>
<td>Neither process nor outcome (no reasoning, incorrect answer)</td>
<td>2/83 (2%)</td>
</tr>
</tbody>
</table>
You have isolated three mutants that all have the same basic phenotype of excess cell survival (too few or no cell deaths). What are the normal functions of the corresponding gene(s)?

a) To promote cell death.
b) To prevent cell death.
c) Not yet enough information to decide.
Transcript: process and outcome productive

Student 1: The question asks what are normal functions of the gene. It seems that if they get apoptosis normally then they would promote cell death. So I said A.
Student 2: That’s what I said, A.
Student 3: I said C, how do you know?
Student 1: I just assumed that if normally they get apoptosis and it’s mutated then it must be promoting it somehow.
Student 3: What if they are preventing it and they are super turned on or something?
Student 4: They could do either, it’s a trick question.
Student 1: I guess it’s possible.
Student 4: I guess you don’t have enough information...
Student 1: Yeah, so I guess we don’t know for sure then. I’ve been convinced.

You have isolated three mutants that all have the same basic phenotype of excess cell survival (too few or no cell deaths). What are the normal functions of the corresponding gene(s)?
a) To promote cell death.
b) To prevent cell death.
c) Not yet enough information to decide.
Ultimate goal:

Determine if instructional practices affect clicker discussions

Instructor behaviors to examine:

• Prompting and emphasizing reasoning before the beginning of a clicker question

• Holding students accountable for their reasoning (asking students to explain their ideas to whole class)
## Can Instructor Behavior Influence Discussion?

*Weekly alteration in introduction to clicker discussion*

<table>
<thead>
<tr>
<th>“Answer-oriented” style</th>
<th>“Justification-oriented” style</th>
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</thead>
<tbody>
<tr>
<td>“Discuss with your table and revote, and after that I’ll explain the answer.”</td>
<td>“Discuss with your table, and focus on the reasons for your answers. I’ll ask you to share your reasons.”</td>
</tr>
<tr>
<td>Tables not asked to speak after revote.</td>
<td>Tables asked to give reasons for choice.</td>
</tr>
<tr>
<td>Histogram revealed immediately after revote.</td>
<td>Histogram revealed after students shared ideas.</td>
</tr>
<tr>
<td>Instructor explained answer</td>
<td>Instructor wrapped up discussion (including mentioning correct answer)</td>
</tr>
</tbody>
</table>
Instructor cues impact amount of reasoning

<table>
<thead>
<tr>
<th>Measure</th>
<th>Answer-oriented (n=34)</th>
<th>Justification-oriented (n=49)</th>
<th>Stats</th>
</tr>
</thead>
<tbody>
<tr>
<td>% constructivist (more than one student offering justification for answers)</td>
<td>68%</td>
<td>90%</td>
<td>Different!</td>
</tr>
<tr>
<td>Mean normalized gain</td>
<td>51%</td>
<td>46%</td>
<td>Not different</td>
</tr>
<tr>
<td>Mean fraction of conversation devoted to reasoning</td>
<td>.32 +/- .03</td>
<td>.42 +/- .03</td>
<td>p&lt;.05</td>
</tr>
</tbody>
</table>

Other measures of productivity (social, questioning, etc.) are still under analysis
In summary...

• Asking questions in class is a pedagogical tool that will produce student learning, especially if students are given a chance to discuss their ideas.
• When students are challenged (with difficult questions), they learn from the process of solving such questions.
• Analysis of student conversations may allow us to understand and characterize what makes peer instruction work.

Other projects that may be of interest (feel free to ask!)
- Biology Concept Assessments: development and use
  - Genetics, Intro Molecular and Cell, upcoming: Capstone
- Misconceptions: identifying and repairing ideas in Genetics
- Faculty and Post-Doc development programs: training others to change the way they teach science
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