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Abstract

The U.S. is unique in the variety of teaching methods and curricula used in science and math classrooms. We have mined 20,000 college students’ histories taking critical college “gate-keeper” courses in biology, chemistry, physics, and calculus, putting to the test K-12 educators' beliefs about the kinds of preparatory experiences and key resources that impact both college grades and students’ career choice. I will share findings on the impact of lab experience, graphing calculators, computerized labs and simulations, demonstrations, content coverage, Advanced Placement courses, project work, teacher professional development, and mathematics preparation.
Where should we invest to maximize: STEM Persistence and STEM Performance?
Where should we invest to maximize: STEM Persistence and STEM Performance?

- Advanced Placement
- Block scheduling
- Labs and demonstrations
- Assessment
- Instructional practices

- Technology
- Facts vs Concepts
- Coverage
- Physics First
- Mathematics
- Inquiry
- Teacher Knowledge
Epidemiological Methods

• Retrospective Cohort Studies
  – Quicker than longitudinal methods
  – Relies on accurate recall
  – Tests many hypotheses at the same time
  – When done well, halfway between
    • Correlational and Experimental studies
    • Includes alternative hypotheses & controls
    • Lack of correlation implies lack of causality
Stratified Random Sample
How Does Interest in a STEM Career Change in High School?

- Does it change?
- Is it different by field?
- Are there differences by gender?
How Does Interest in a STEM Career Change in High School

End of High School
Beginning of High School

Males

Engineering: 24.8%
Sciences, Math, Science Teaching: 15.0%
Medicine: 12.7%
Health: 3.0%
Other: 44.5%

End of High School
Beginning of High School

Females

Engineering: 28.3%
Sciences, Math, Science Teaching: 11.0%
Medicine: 7.9%
Health: 6.9%
Other: 46.9%

End of High School
Beginning of High School

24.8% 15.0% 12.7% 3.0% 44.5%
28.3% 11.0% 7.9% 6.9% 46.9%
15.0% 8.7% 19.6% 14.3% 49.1%
5.0% 18.4% 15.0% 18.4% 53.0%

Does HS Coursework Matter?
What the public hears

“It is better to take a tougher course and get a low grade than to take an easy course and get a high grade.”

Clifford Adelman, Senior Research Analyst, U.S. Dept. of Ed.
Does HS Coursework Matter?

The diagram shows the probability of STEM career interest for students who took AP courses in various subjects compared to those who did not. The x-axis represents the number of years of subject study, and the y-axis represents the change in probability from not taking the course. The subjects include Calculus (Calc), Biology (Bio), Chemistry (Chem), Physics (Phys), and Other (Othr). The data points indicate a slight increase in interest for students who took the courses, with a range of effects depending on the subject and the number of years of study.
Gender Issues


Plotkin, G, Hazari, Z., & Sadler, P.M., (in press) Unraveling Bias from Student Evaluations of their Science Teachers, *Science Education*
Career Variables for College Freshmen by Field and Gender

N=5570 students at 40 randomly chosen U.S. colleges

Units in standard deviation from the mean, bubble areas reflect N

Importance of External Rewards
Compensation, Fame, Status

Importance of Other People
Working with others, Helping others

Preliminary Findings, not for publication
Interest in a STEM Career at the end of high school by career interest at the start of high school.

Carrer Interest at the Start of High School

Non-STEM Career

- Eng/Language Arts Spec.
- Other Teacher
- Other Non Science Career
- Business Person
- Medical Professional
- Social Scientist
- Health Professional
- Lawyer
- Earth/Env. Scientist
- Biologist
- Science Teacher
- Math Teacher
- Astronomer
- Computer Scientist
- Chemist
- Engineer
- Mathematician
- Other Scientist
-Physicist

STEM Career

- Astronomer
- Chemist
- Engineer
- Mathematician
- Other Scientist
- Physicist

female
male
Is there a connection between students' participation in OST activities and their STEM career intention?

Table 2. Logistic regression model summary with odds ratio

<table>
<thead>
<tr>
<th></th>
<th>B</th>
<th>Sig.</th>
<th>SE</th>
<th>Odds ratio</th>
</tr>
</thead>
<tbody>
<tr>
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<td>-4.943</td>
<td>***</td>
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<td>0.007</td>
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<td>Gender</td>
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<td>0.819</td>
<td>0.019</td>
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<td>Socioeconomic status</td>
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<td>0.000</td>
<td>1.000</td>
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<tr>
<td>Race/Ethnicity</td>
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<tr>
<td>East Asian</td>
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<td>0.817</td>
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<tr>
<td>Caucasian</td>
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<td>0.110</td>
<td>0.993</td>
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<tr>
<td>African-American</td>
<td>-0.006</td>
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<td>0.163</td>
<td>0.994</td>
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<tr>
<td>MS interest</td>
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<td></td>
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<td></td>
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<tr>
<td>Science</td>
<td>0.592</td>
<td>***</td>
<td>0.090</td>
<td>1.808</td>
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<tr>
<td>Math</td>
<td>0.664</td>
<td>***</td>
<td>0.093</td>
<td>1.904</td>
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<tr>
<td>MS grade</td>
<td></td>
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<tr>
<td>Science</td>
<td>0.013</td>
<td>0.875</td>
<td>0.083</td>
<td>1.013</td>
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<tr>
<td>Math</td>
<td>0.399</td>
<td>***</td>
<td>0.079</td>
<td>1.490</td>
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<tr>
<td>OST clubs/Competitions</td>
<td>0.409</td>
<td>***</td>
<td>0.086</td>
<td>1.506</td>
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<tr>
<td>OST reading/Watching</td>
<td>0.287</td>
<td>**</td>
<td>0.084</td>
<td>1.332</td>
</tr>
</tbody>
</table>

*p < 0.05, **p < 0.01, ***p < 0.001.
Pedagogy used in HS science classrooms:

impact on STEM Career Interest?

impact on rating of teacher quality?
### Does Pedagogy Impact STEM Career Interest?

<table>
<thead>
<tr>
<th>Answered questions</th>
<th>Focus on conceptual understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connected to every-day life</td>
<td>Current events</td>
</tr>
<tr>
<td>Asked questions</td>
<td>frequency of unisex lab groups</td>
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<tr>
<td>Connected to other disciplines</td>
<td>frequency of work requiring calculations</td>
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<tr>
<td>Small group work</td>
<td>frequency of work requiring long explanations</td>
</tr>
<tr>
<td>Others answered questions</td>
<td>Hands-on/lab work</td>
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<tr>
<td>Whole group discussion</td>
<td>Individual work</td>
</tr>
<tr>
<td>Field trips</td>
<td>labs addressed world views</td>
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<tr>
<td>Guest speakers</td>
<td>memorization</td>
</tr>
<tr>
<td>Science videos</td>
<td>role of textbook</td>
</tr>
<tr>
<td>Taught classmates</td>
<td>Teacher lectured</td>
</tr>
<tr>
<td>Tests/Quizzes</td>
<td>Teachers personal science experiences</td>
</tr>
<tr>
<td>Work of female scientists</td>
<td>Test or Quiz questions Could be solved w/o math</td>
</tr>
<tr>
<td>Benefits of being a scientist</td>
<td>Test or Quiz questions Material covered on previous tests/quizzes</td>
</tr>
<tr>
<td>Under-representation of women in science</td>
<td>Test or Quiz questions Required long written responses</td>
</tr>
<tr>
<td>Science career stages and options</td>
<td>Test or Quiz questions Required sketching/drawing</td>
</tr>
<tr>
<td>Ethics in science</td>
<td></td>
</tr>
<tr>
<td>Guest female scientists</td>
<td></td>
</tr>
<tr>
<td>Test or Quiz questions Drawn from homework</td>
<td></td>
</tr>
<tr>
<td>Test or Quiz questions Involved data analysis</td>
<td></td>
</tr>
<tr>
<td>Test or Quiz questions Multiple choice/tf</td>
<td></td>
</tr>
<tr>
<td>Test or Quiz questions Required calculations</td>
<td></td>
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</table>
## Does Pedagogy Impact STEM Career Interest?

<table>
<thead>
<tr>
<th></th>
<th>Biology</th>
<th>Chemistry</th>
<th>Physics</th>
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<tbody>
<tr>
<td></td>
<td>D1  D2  D3  D4</td>
<td>D1  D2  D3  D4</td>
<td>D1  D2  D3  D4</td>
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<tr>
<td>Answered questions</td>
<td>0.79  0.01  0.04  0.11</td>
<td>0.76  0.00  0.06  0.07</td>
<td>0.79  0.04  0.08  0.05</td>
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<tr>
<td>Connected to every-day life</td>
<td>0.66  0.09  0.18  0.08</td>
<td>0.70  0.08  0.27  0.01</td>
<td>0.70  0.07  0.16  0.13</td>
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<td>Asked questions</td>
<td>0.69  0.02  0.08  0.11</td>
<td>0.66  0.01  0.06  0.11</td>
<td>0.70  0.07  0.07  0.08</td>
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<td>Connected to other disciplines</td>
<td>0.63  0.14  0.18  0.06</td>
<td>0.65  0.10  0.26  0.01</td>
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<td>Small group work</td>
<td>0.54  0.20  0.06  0.00</td>
<td>0.63  0.14  0.00  0.08</td>
<td>0.60  0.15  0.07  0.01</td>
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<tr>
<td>Others answered questions</td>
<td>0.53 -0.06  0.01  0.22</td>
<td>0.54 -0.05  0.00  0.22</td>
<td>0.61 -0.03  0.05  0.17</td>
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<td>Whole group discussion</td>
<td>0.53  0.08  0.09  0.03</td>
<td>0.51  0.09  0.10  0.11</td>
<td>0.54  0.07  0.11  0.07</td>
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<td>Field trips</td>
<td>-0.02  0.83  0.06  -0.09</td>
<td>-0.05  0.84  0.11  -0.14</td>
<td>-0.07  0.80  0.10  -0.10</td>
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<td>Guest speakers</td>
<td>-0.03  0.85  0.05  -0.09</td>
<td>-0.06  0.83  0.12  -0.14</td>
<td>-0.07  0.78  0.10  -0.10</td>
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<tr>
<td>Science videos</td>
<td>0.08  0.62  0.02  -0.06</td>
<td>0.06  0.61  0.08  -0.07</td>
<td>0.04  0.59  0.07  -0.04</td>
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<td>Student taught classmates</td>
<td>0.16  0.51  0.06  -0.06</td>
<td>0.15  0.48  0.08  -0.04</td>
<td>0.18  0.42  0.07  -0.05</td>
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<td>Frequent Feedback from Tests/Quizzes</td>
<td>0.16  0.44  0.05  0.01</td>
<td>0.21  0.45  0.05  0.09</td>
<td>0.15  0.48  -0.02  0.10</td>
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<tr>
<td>Work of female scientists</td>
<td>0.06  0.06  0.60  -0.01</td>
<td>0.05  0.05  0.48  0.01</td>
<td>0.01  0.09  0.57  -0.01</td>
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<tr>
<td>Benefits of being a scientist</td>
<td>0.09  0.05  0.52  0.16</td>
<td>0.06  0.02  0.52  0.11</td>
<td>0.10 -0.01  0.54  0.17</td>
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<tr>
<td>Under-representation of women in science</td>
<td>0.02  0.07  0.55  -0.06</td>
<td>0.03  0.04  0.46  -0.07</td>
<td>0.03  0.11  0.45  -0.05</td>
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<tr>
<td>Science career stages and options</td>
<td>0.10  0.06  0.52  0.15</td>
<td>0.12 -0.03  0.45  0.24</td>
<td>0.14 -0.04  0.48  0.24</td>
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<td>Ethics in science</td>
<td>0.10  0.02  0.46  0.25</td>
<td>0.07  0.06  0.46  0.16</td>
<td>0.10  0.03  0.43  0.15</td>
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<tr>
<td>Guest female scientists</td>
<td>0.02  0.11  0.48  -0.12</td>
<td>-0.01  0.13  0.40  -0.13</td>
<td>-0.04  0.19  0.39  -0.08</td>
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<tr>
<td>Test or Quiz questions Required memorization</td>
<td>0.02 -0.08 -0.06  0.58</td>
<td>-0.01 -0.05  0.08  0.44</td>
<td>0.11 -0.02  0.11  0.37</td>
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<tr>
<td>Test or Quiz questions Drawn from homework</td>
<td>0.06 -0.04  0.02  0.45</td>
<td>0.04 -0.07  0.08  0.42</td>
<td>0.09 -0.06  0.05  0.43</td>
</tr>
<tr>
<td>Test or Quiz questions Involved data analysis</td>
<td>0.06  0.04  0.14  0.40</td>
<td>0.04 -0.03  0.15  0.35</td>
<td>0.26  0.33  0.10  0.10</td>
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<tr>
<td>Test or Quiz questions Multiple choice/tf</td>
<td>0.04 -0.05 -0.08  0.45</td>
<td>-0.01 -0.06  0.09  0.35</td>
<td>0.02  0.12  0.10  0.37</td>
</tr>
<tr>
<td>Test or Quiz questions Required calculations</td>
<td>0.04  0.14  0.17  0.13</td>
<td>0.04 -0.14 -0.01  0.43</td>
<td>0.12 -0.03  0.07  0.46</td>
</tr>
</tbody>
</table>

Preliminary Findings, not for publication
Does Pedagogy Impact STEM Career Interest?

Preliminary Results, not for publication
To what degree does having a STEM teacher with the same gender impact student interest in a STEM career?

Logistic Regression on End of HS STEM Interest

<table>
<thead>
<tr>
<th>Variable</th>
<th>DF</th>
<th>Prob</th>
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</thead>
<tbody>
<tr>
<td>Constant</td>
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<td>≤ 0.0001</td>
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<tr>
<td>Beginning of HS STEM Interest</td>
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<td>≤ 0.0001</td>
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<tr>
<td>Father's Education</td>
<td>6</td>
<td>0.0601</td>
</tr>
<tr>
<td>Mother's Education</td>
<td>6</td>
<td>0.8317</td>
</tr>
<tr>
<td>Father's Career</td>
<td>1</td>
<td>≤ 0.0001</td>
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<tr>
<td>Mother's Career</td>
<td>1</td>
<td>0.8455</td>
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<tr>
<td>q12act_satm</td>
<td>1</td>
<td>≤ 0.0001</td>
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<tr>
<td>Student Gender (Male=1)</td>
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<td>≤ 0.0001</td>
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<tr>
<td># science courses</td>
<td>1</td>
<td>≤ 0.0001</td>
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<td>Fraction Male Teachers</td>
<td>1</td>
<td>0.8603</td>
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<tr>
<td>Interaction: Teacher Gender * Student Gender</td>
<td>1</td>
<td>0.3428</td>
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</tbody>
</table>

Preliminary Findings, not for publication
Persistence

- STEM interest shifts in HS
- Engineering > science & math
- HS volatility higher for females
- HS coursework impacts interest
  - Bio: - for years; no impact for AP
  - Chem: + for 2 years; none for AP
  - Phys: + for years; no impact for AP
  - Math: + for calc; no impact for AP

- People orientation
  - Low for STEM, high for Med/Health
  - Higher for females

- Extrinsic Reward orientation
  - Higher for males
  - Engineering > science and math

- Science reading/watching and OST clubs and competitions
- Discuss challenges and benefits of a STEM career
- Humanistic Pedagogy
- No “role model” effect
Sadler’s Conundrum

Teachers’ Claim:

*I prepare students well for success in their next course.*

Professors’ Claim:

*Students are not well prepared for success in my course.*
Performance in Introductory College Courses

- Studying Science Gatekeeper Courses
  - STEM & Medicine
  - Grades based on professor’s assessments
  - Authentic measure
Does the Order in Which Science Courses Are Taken Make a Difference?

Testing the *Physics First* Hypotheses

1. **Taking more physics will have a positive impact on later learning in chemistry.**

2. **Taking more chemistry will have a positive impact on later learning in biology.**
HS Biology

Difference in College Grade

College Biology  College Chemistry  College Physics

Legend:
- HS Biology
- HS Chemistry
- HS Physics
- HS Mathematics
HS Chemistry Effect

Difference in College Grade

College Biology  College Chemistry  College Physics

- HS Biology
- HS Chemistry
- HS Physics
- HS Mathematics
HS Physics Effect

Difference in College Grade

College Biology  College Chemistry  College Physics

HS Biology  HS Chemistry  HS Physics  HS Mathematics
Is HS calculus for everyone?


Performance in College Calculus

Preliminary Findings, not for publication
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- Humanistic Pedagogy
- No “role model” effect

Performance in College

- Prepare for
  - science with same science & math
  - calculus with HS calculus
  - HS calculus helps all students
Pedagogy and Curriculum


The Impact of Coverage: Depth vs. Breadth

- In teaching my high school science course so that students are well-prepared for college science, I make sure that we cover:
  - All the major topics so that students are familiar with most terms and concepts
  - A few key topics in great depth so that students have mastered essential foundational concepts
The Impact of Coverage: Depth vs. Breadth

- % in Each High School Group:
  - Biology
  - Chemistry
  - Physics

- Difference in College Grade:
  - Biology
  - Chemistry
  - Physics

Legend:
- All topics covered. Same time for each.
- Fewer topics. Same time for each.
- All topics covered. Extra time for 1 or 2.
- Fewer topics. Extra time for 1 or 2.
Laboratory Activities


What Appears to:

**Help:**
- Often Draw/Interpret Graphs by Hand
- Often Analyzed Pictures or Illustrations
- Labs Addressed Student’s Beliefs
- More prediction, less demo discussion
- Focus on key foundational concepts
What Appears to:

Help:
- Often Draw/Interpret Graphs by Hand
- Often Analyzed Pictures or Illustrations
- Labs Addressed Student’s Beliefs
- More prediction, less demo discussion
- Focus on key foundational concepts

Hinder:
- Emphasis on lab procedure
  - Read & Discuss Labs a Day Before
  - Doing labs only once
- Testing on labs vs. reports
- Demonstrations with no predictions
Persistence

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• Discuss challenges and benefits of a STEM career
• Humanistic Pedagogy
• No “role model” effect

Performance in College

• Prepare for
  – science with same science & math
  – calculus with HS calculus
  – HS calculus helps all students
• Coverage
  – Less content, more mastery
• Pedagogy
  – Pictures, illustrations, graphs
  – Simplify lab and demo prediction
Paths to College Calculus

Other 12th grade math course

12th grade "gap" year

Preliminary Findings, not for publication
HS Calculus Teacher Choices

Positive Practices
- Heavy emphasis on functions
- Review homework daily
- Emphasize conceptual understanding
- Emphasize vocabulary

Negative Practices
- Plotting graphs on calculator
- “cheat sheets” for tests
- preparing for tests
- reviewing past lessons
- Teacher manipulates physical objects as teaching aids
How effective are we at teaching foundational concepts?
Clinical Interviews

On-on-one with students

Minds of Our Own consists of 3-one hour programs broadcast on PBS in 1997-98. It explores the ideas of students as they come to understand scientific concepts.

A Private Universe documents students’ ideas through their own drawings and explanations.

www.ficss.org
www.learner.org
Both students and teachers have (or had) preconceptions

- Exist prior to formal instruction
- At odds with accepted scientific thought, “misconceptions”
- Commonly held, not idiosyncratic
- Embedded in larger knowledge structures, not just a simple “error” (that is easy to correct)
- Resistant to change, over-estimation of $\Delta$
- Best teachers can predict their occurrence
Methods for assessing conceptions

- **Interviews**
  - Lengthy and costly
  - Well-trained interviewer
- **Open-ended items:**
  - Students might not explain their thinking
  - Misconceptions might not be uncovered
  - Difficult and time consuming to score
- **Multiple-Choice items**
  - Must know misconceptions beforehand
  - Must include misconceptions as distractors
  - Other items are too easy
Patterns in Test Data
### 5-8 MOSART Middle School Life Science Field Test

<table>
<thead>
<tr>
<th>Topic</th>
<th>Teachers, n=209</th>
<th>Students, n=20936</th>
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</thead>
<tbody>
<tr>
<td>Organization Levels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B  Cell = Basic Unit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C  Cell Functions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D  Tissues &amp; Organs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E  Organism Systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F  Disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A Reproduction Essential</td>
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</tr>
<tr>
<td>B Sexual Reproduction</td>
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<td>C Heredity</td>
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<td>D Genes &amp; Traits</td>
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<td>E Heredity &amp; Environment</td>
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<td>A Survival</td>
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<td>B Homeostasis</td>
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<td>C Behavioral Response</td>
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<td>D Behavior &amp; Evolution</td>
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<td>E Survival vs...</td>
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<td>B Population Types</td>
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<td>C Ecosystems Solar...</td>
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<td>D Population Controls</td>
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<td>A Common Ancestry</td>
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<td>B Evolution</td>
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<tr>
<td>C Extinction</td>
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### Key
- **Teachers, n=209**
- **Teachers Prediction s, n=209**
- **Students, n=20936**

### Topics
- **I. Structure and function**
- **II. Reproduction and Regulation**
- **III. Populations**
- **IV. Diversity**
Teacher Knowledge, MS-LS

Pedagogical Content Knowledge (PCK)

Subject Matter Knowledge (SMK)
Yearly Classroom Gain in Middle School Physical Science Courses, N= 15029 students of 160 teachers

Concepts without Strong Misconceptions

Concepts with Strong Misconceptions

Effect Size (in Units of Standard Deviation)

Item Type and Teacher Knowledge

No SMK | SMK | No SMK | SMK Only | SMK & PCK

| No Misconception | Misconception |

SMK=Subject Matter Knowledge (knows correct answer)
PCK=Pedagogical Content Knowledge (can identify student misconceptions)
Persistence
- STEM interest shifts in HS
- Engineering > science & math
- HS volatility higher for females
- HS coursework impacts interest
  - Bio: - for years; no impact for AP
  - Chem: + for 2 years; none for AP
  - Phys: + for years; no impact for AP
  - Math: + for calc; no impact for AP
- People orientation
  - Low for STEM, high for Med/Health
  - Higher for females
- Extrinsic Reward orientation
  - Higher for males
  - Engineering > science and math
- Science reading/watching and OST clubs and competitions
- Discuss challenges and benefits of a STEM career
- Humanistic Pedagogy
- No “role model” effect

Performance in College
- Prepare for
  - science with same science & math
  - calculus with HS calculus
  - HS calculus helps all students
- Coverage
  - Less content, more mastery
- Pedagogy
  - Pictures, illustrations, graphs
  - Simplify lab and demo prediction
- Students maintain misconceptions
  - often unchanged after taking science
- Teacher knowledge
  - Subject matter necessary
  - Knowledge of misconceptions essential
Welcome to MOSART

"I'm teaching, but they're not learning!"

This is one of the most common laments from educators. Your students may perform well on your assessment instruments, yet say things in class which leave you wondering if they really understand the underlying concepts. Or perhaps you're at the beginning of a unit and are unsure about what your students already know. Which concepts do they already grasp, and which will you have to address? If any of these doubts and questions sound familiar, then the MOSART project was designed to help you.

The acronym MOSART stands for:

- Misconceptions-Oriented: The project recognizes that students do not come to your class as "blank slates" but rather have their own theories.
- Standards-based: The NRC NSES comprise a unifying thread among all MOSART items and tests.
- Assessment Resources for Teachers: The project provides educators with multiple-choice tests that can be used to assess their students' understanding of this content.
Annenberg Channel
free videos and PD

Assessment in Math and Science: What’s the Point?

A video workshop for K-12 teachers; 8 ninety-minute video programs, workshop guide, and Web site; graduate credit available.

"Will this be on the test?" "Is this going to count?" How often do students ask these questions? This workshop examines current assessment issues and strategies in K-12 math and science classrooms. Through video segments of real classrooms interspersed with lively discussions of practicing teachers and content experts, see how teachers deal with common issues and discover ways to improve teaching and learning.

Produced by the Harvard-Smithsonian Center for Astrophysics and Massachusetts Corporation for Educational Telecommunications (MCET). 1997.


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Private Universe Project in Science
Factors Influencing College Science Success
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