Implementing Curricular Reform in a Large Lecture Course at Georgia Tech

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Introductory Physics @ Georgia Tech

+ Two-semester sequence
  Semester 1—Mechanics, Semester 2—E&M

+ ~1600 students per semester
+ 83% engineering, 17% science majors
+ Three lecture hours per week
  (200 students per lecture section)
+ One weekly lab/recitation (3 contact hours)
  (20 students per lab/recitation section)
Shortcomings of Traditional Curriculum

+ Content unchanged for decades
  - 19th century (or earlier) concepts
  - Focus on analytic solutions of special cases

+ Difficulties at GT
  - GPA lower than other intro courses
  - High D/F/W rate (as high as 25%)
  - Unpopular with students
  - External review criticized structure, outcomes
Reform Curriculum: Matter and Interactions (M&I)
(R. Chabay & B. Sherwood, Wiley, 2010)

Modern content
+ Fundamental principles
+ Atoms and structure of matter
+ Relativity and quantum physics
+ Macro/micro connections

Modern tools/techniques
+ Computer modeling
Infrastructure Preparation

+ Local expert: Hire Postdoc (1/06-9/08)

+ Train Teaching Assistants
  (Spring 06, on-going)

+ Laboratory Equipment Purchase/Construction
  (Spring 06, Fall 07)
Faculty Preparation: Apprenticeship Model

+ Junior faculty---pair with experienced instructor, provide logistical support.

+ Senior faculty---same plus financial incentive
## Gradual Implementation

<table>
<thead>
<tr>
<th>Semester</th>
<th>M&amp;I Semester 1</th>
<th>M&amp;I Semester 2</th>
<th>Faculty w/M&amp;I experience</th>
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<tbody>
<tr>
<td>Summer 06</td>
<td>40 students</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>Fall 06</td>
<td>120 students</td>
<td>45 students</td>
<td>1</td>
</tr>
<tr>
<td>Spring 07</td>
<td>200 students</td>
<td>150 students</td>
<td>2</td>
</tr>
<tr>
<td>Summer 07</td>
<td>None</td>
<td>150 students</td>
<td>3</td>
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<tr>
<td>Fall 07</td>
<td>150 students</td>
<td>300 students</td>
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<tr>
<td>Spring 08</td>
<td>300 students</td>
<td>300 students</td>
<td>4</td>
</tr>
<tr>
<td>Summer 08</td>
<td>150 students</td>
<td>150 students</td>
<td>4</td>
</tr>
<tr>
<td>Fall 08</td>
<td>300 students</td>
<td>450 students</td>
<td>6</td>
</tr>
<tr>
<td>Spring 08</td>
<td>500 students</td>
<td>300 students</td>
<td>6</td>
</tr>
<tr>
<td>Summer 09</td>
<td>250 students</td>
<td>None</td>
<td>6</td>
</tr>
<tr>
<td>Fall 09</td>
<td>400 students</td>
<td>550 students</td>
<td>7</td>
</tr>
</tbody>
</table>
Is reform doing any good?

Compare student performance
Traditional (control) vs M&I (reform)

In class measurements
  + Concept inventories
  + Common final exam problems.
  + Performance in follow-on courses.

Out of class measurements
  + Think aloud protocol studies
Brief Electricity & Magnetism Assessment (BEMA)

- Standardized multiple choice test
  • (31 questions)
- Qualitative and short quantitative questions
- Covers topics *common to both M&I and traditional course*
- Administer “pre-test” at beginning of course, “post-test” at end, measure gains
Semester 2 (E&M) Concept Inventory
Reform Outperformance

![Bar chart showing average BEMA scores for different institutions and teaching methods.](chart.png)

- **GT**
  - M&I N=612
  - TRAD N=1246

- **Purdue**
  - M&I N=76
  - TRAD N=78

- **NCSU**
  - M&I N=79
  - TRAD N=48

- **CMU**
  - M&I N=73
  - TRAD N=116

*Error bounds (95% Confidence Intervals) are ±2 σ.*

Average BEMA Score (%) (Post-Instruction)
Score Distributions at Georgia Tech

Pre-test
\[ \bar{X}_{\text{MI}} = 25.9\%, \quad \bar{X}_{\text{TRAD}} = 24.8\% \]

Post-test
\[ \bar{X}_{\text{MI}} = 58.2\%, \quad \bar{X}_{\text{TRAD}} = 46.1\% \]
Concept Inventory—Semester 1 (Mechanics)

Force Concept Inventory (FCI)
- Standardized multiple choice test
  - (30 questions)
- Qualitative questions
- Administer “pre-test” at beginning of course, “post-test” at end, measure gains
Semester 1 (Mech.) Concept Inventory
Traditional Outperformance

Georgia Tech

Error bounds
are 95% Confidence Intervals
(± 2 σ)

Average FCI Score (%)
Common Final Exam Questions
Similar (Dismal) Performance

Percentage of “Mostly Correct” Responses

<table>
<thead>
<tr>
<th>Question</th>
<th>TRAD.</th>
<th>M&amp;I</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mech. 1</td>
<td>13%</td>
<td>26%</td>
</tr>
<tr>
<td>Mech. 2</td>
<td>29%</td>
<td>24%</td>
</tr>
<tr>
<td>Mech. 3</td>
<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>Mech. 4</td>
<td>21%</td>
<td>17%</td>
</tr>
<tr>
<td>Mech. 5</td>
<td>59%</td>
<td>49%</td>
</tr>
<tr>
<td>E&amp;M 1</td>
<td>10%</td>
<td>17%</td>
</tr>
<tr>
<td>E&amp;M 2</td>
<td>22%</td>
<td>39%</td>
</tr>
<tr>
<td>E&amp;M 3</td>
<td>20%</td>
<td>29%</td>
</tr>
</tbody>
</table>
Average GPA in Advanced Courses
Similar Performance

COE 2001 (Engineering Statics)
(Requires Mechanics Prerequisite)
  Trad: 2.79 (+/- 0.05) (N=1695)
  M&I: 2.81 (+/- 0.11) (N=359)

ECE 3025 (Electromagnetics)
(Requires E&M Prerequisite)
  Trad: 2.93 (+/- 0.15) (N=144)
  M&I: 2.95 (+/- 0.28) (N=24)
Adopt Semester 2 reform, Hybridize Semester 1 (Final Decision Pending)

+ Faculty Discussion:
  * Not (strongly) data-driven
  * Testimony of participating faculty given significant consideration.
  * Computation/Visualization: accepted prima facie as significantly positive
Lessons Learned: Implementing Sustainable Reform in Large Lecture Courses
More and Better Measurements NEEDED

+ Measurements are difficult

+ Beware of overreliance on particular measurements (Concept Inventories)
E&M Concept Inventory: BEMA

Reform Outperformance


Error bounds (white) are 95% Confidence Intervals (± 2 σ)

GT
- M&I N=612
- TRAD N=1246

Purdue
- M&I N=76
- TRAD N=78

NCSU
- M&I N=79
- TRAD N=48

CMU
- M&I N=73
- TRAD N=116

Average BEMA Score (%) (Post-Instruction)
E&M Concept Inventory: CSEM
Traditional Outperformance
Georgia Tech (Fall 09)

- TRAD N=282
- M&I N=517
- TRAD N=428
- M&I N=524

Error bounds are 95% Confidence Intervals (± 2 σ)
Are BEMA & CSEM Equivalent?

S. Pollock, PERC Proceedings (2008): Yes, (for same (Traditional) curriculum)

Equivalent for different curricula?

More (and different) measurements needed
More Interdisciplinary Work NEEDED

+ Content specialists largely ignorant of psychological, social, cognitive dimensions of teaching and learning
Example: Cognitive-Science-Inspired: Curricular Reform

Core Mechanics Knowledge

PRINCIPLES
Momentum
Energy
Angular Momentum

Motion
\( t, \Delta t, \vec{v}, \Delta \vec{v}, a, \vec{p}, \Delta \vec{p} \)

Interactions
\( \vec{F}, \text{potential energy} \)

Chabay & Sherwood (2010); Reif (2008)
Think-aloud protocol study
Semester 1 Concept Inventory

+ Individual interview of volunteers who work problems while narrating their thoughts
+ Analysis of interview Audio/Video records (Work in progress)

Average % Score of Concept Inventory Questions
Think-aloud protocol study
FCI Concept Inventory

+ RESULT:
NO M&I participants used a Fundamental Principle!

Average % Score of Concept Inventory Questions
Principle-based Curriculum for Novices?

M&I course exercises (homework, labs, etc) developed in Traditional way

Develop exercises using cognitive science systematically?

Interdisciplinary work needed
Task analysis

• Determine the knowledge and procedures needed to solve classes of problems
  – May be different for novices and experts!
  – Experts may have “hidden” or “compiled” knowledge

• “Professional novice” (Catrambone)
  – Examines expert working on physics problems from M&I course
  – Reconstructs necessary steps
  – Builds general procedure

• Compare student problem solving to task analysis
  – Do they follow same procedure?
  – What pieces are they missing?
Tighter Integration of Computation/Visualization NEEDED

+ M&I Student Experience: Lab only

+ Significant Computational Anxiety
Computational Homework

+ Modify lab-developed code to investigate new questions

+ Problems highly-customized to each student

+ Heavy use of visualization to build student intuition

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Weather Balloon Trajectory
blue arrow represents $\vec{F}_{\text{net}}$
Computational Homework

For more details:

See Talk GG04: (TUESDAY 7:36pm, Washington I) Marcos Caballero
“Computational Exercises in Introductory Mechanics”
(Session GG: Teaching with Technology III)
Summary

Curriculum Implementation Keys:
+ Local expert (teaching postdoc)
+ Go slow (build infrastructure)

Strengthen Sustainability:
+ More and better measurements
+ Improve exercises (w/ Cognitive Science)
+ Tighter integration of computation

http://www.physics.gatech.edu/gtper