The performance of 5000 students in introductory mechanics

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Two Courses taught at GT

• Introductory Mechanics
  • A “standard” course based on Knight
  • The Matter and Interactions course

• ~800 students per semester take introductory mechanics

• 83% engineering, 17% science majors

• Large classroom setting (150-250 students)

• Labs/Recitations (15-25 students)
A Standard Mechanics Course

- Covers the usual topics (projectile motion, friction, statics, circular motion, etc.)
- Usual organization of topics (kinematics, dynamics, energy, angular momentum, etc.)
- Emphasis during force and motion section - constant force motion, kinematic equations, free body diagrams
- At GT, use the Knight text
  3 hour lecture (with “clicker” questions)
  2 hour laboratory, 1 hour recitation
Online homework system - Mastering Physics
Matter and Interactions

www.matterandinteractions.org

• Emphasizes on a principle based approach (Impulse-Momentum Theorem, Energy Principle, Angular Momentum Principle)

• Introduces the ball and spring model of matter and connects microscopic to macroscopic

• Uses modern tools (simulation and visualization)

• 3 hour lecture (with “clicker” questions)
  3 hour lab/recitation
Online homework system - WebAssign
Comparing the Courses

• Courses have markedly different curricula (course content and structure) making comparison a complex undertaking

• Proper comparison requires multiple metrics, e.g.
  • Standardized assessments
  • Student interviews (think aloud)
  • Common final exam problems
  • Complex (non-standard) problems

• Standardized assessments require smallest infrastructure, easy to score
Measuring Performance using the Force Concept Inventory

- 30 item multiple-choice test covers force and motion
- Emphasizes constant force motion and contains strong distractors
- Essential demographic data not statistically different
- Pedagogy (interactivity, presentation, etc.) very similar

TRAD outperforms M&I (Mean FCI score: 71.3% vs 59.3%)
TRAD Performs Better Across Topics

- A priori categorization of topics by experts
- Calculate % a given question contributes to total difference (TRAD-M&I)
Think-Aloud Study

- Audio and video record subjects solving subset of 10 questions
- Subset had higher than average contributions to the difference in scores
- Participants: TRAD, n = 20 and M&I, n = 14

![Bar chart showing average % score on subset of FCI questions]

- In-class FCI:
  - TRAD: N=1983
  - M&I: N=733
- Think Aloud Participants:
  - TRAD: N=20
  - M&I: N=14

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Suggestive Results from Transcript Analysis

• M&I students fail to employ the Impulse-Momentum Theorem
  (NO mention of momentum at all)
• M&I students confuse components of the net force and forces associated with agents
• Revert to naive or incorrect notions of force and motion
• Revert to (often, incorrect/incomplete) memory of high school physics
Homework Questions

- Both courses require students to complete 3 homework assignments per week
- Questions covering FCI topics appearing in homework sets were counted
- Larger fraction of standard course items cover FCI topics
- TRAD ~30% vs M&I ~10%
Concluding Remarks

- TRAD students outperform M&I students on in-class FCI
- Think aloud study identifies M&I students’ shortcomings
- Homework questions suggest exposure to FCI-like items in M&I is limited compared to standard course
- Other metrics currently under evaluation
- Development of materials to foster M&I students’ fluency on force and motion items has begun
- More info: www.physics.gatech.edu/gtper
Why this difference?

- Essential Demographics are identical
- M&I aims to illustrate generality of physics principles
  - De-emphasis of constant force motion
  - Analysis of systems often uses modeling (Languages different: Sherin, 1997)
  - Taught general procedures instead of being given “canned” kinematic formulae
  - More difficult to link several tasks into one goal versus using a “prescribed” method (Catrambone, 2006)
- FCI emphasizes constant force motion
  - TRAD well trained by their curriculum
  - Items similar to FCI appear on PRS, recitation, etc.
- “Think-aloud” study to illuminate underlying issues
An Example from the Think-Aloud Study

- Correct Response (C) - 90% TRAD, 57% M&I,
  Major distractors (A & D) - 10% TRAD, 36% M&I

<table>
<thead>
<tr>
<th>Solution</th>
<th>TRAD (%)</th>
<th>M&amp;I (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Determined acceleration was constant</td>
<td>0</td>
<td>36</td>
</tr>
<tr>
<td>“mass doesn’t matter”</td>
<td>60*</td>
<td>21</td>
</tr>
<tr>
<td>use of kinematics equations</td>
<td>40</td>
<td>0</td>
</tr>
<tr>
<td>recall from previous exercise</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

*Half of these students also used kinematic equations
Item Analysis using Fractional Differences

- Comparing Performance per Question
  - Performance gauged by Raw Gain: \( G = \text{Post} \% - \text{Pre} \% \)
  - Questions can be grouped by Topic

- Computing Fractional Differences
  - Total Difference: \( \Delta G = G_{\text{TRAD}} - G_{\text{M&I}} \)
  - Item Difference: \( \Delta G_i = G_{i,\text{TRAD}} - G_{i,\text{M&I}} \)

- Ratio, \( \Delta G_i/\Delta G \), gives fractional difference
  \( \Delta G_i/\Delta G > 0.033 \), question contribution is greater than if each question contributed equally.)