Implementing and Assessing a New Introductory Physics Course at Georgia Tech

Matthew Kohlmyer[1]
Michael Schatz[1]
Richard Catrambone[2]
M. Jackson Marr[2]

Georgia Institute of Technology
[1]School of Physics
[2]School of Psychology

Supported by NSF DUE-0618519 and Georgia PRISM, Atlanta Metro Region

Intro Physics at Georgia Tech

- Large enrollment (>1700 students per semester, total)
- Large lectures (150-200 students, 3 hr/wk)
- Lab sections (20 students, 3 hr/wk)
- Problems:
  - GPA significantly lower than other intro courses
  - High D/F/W rate (as high as 25%)
  - Unpopular with students
  - External review committee criticized structure, outcomes of intro courses

Issues with traditional intro physics

- Lack of modern content
  - No 20th century physics
  - Macroscopic systems—no atoms!
- Incomplete or ineffective approach to problem-solving
  - Equation-hunting & problem-matching
  - No computer modeling
- Inadequate for preparing future scientists and engineers
  - Nanotechnology, materials science, bioengineering
  - ABET curriculum criteria, 2008-09:
    - Analytic, experimental, and *computational* methods emphasized by several programs

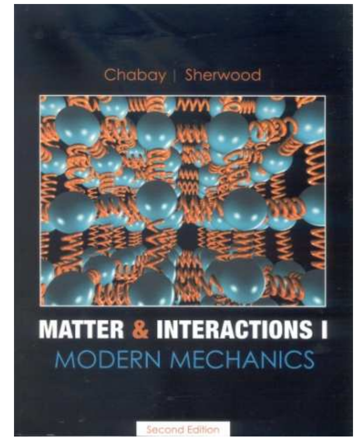
New physics course

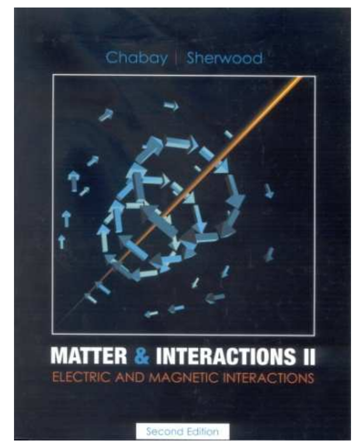
- GT School of Physics using ***Matter & Interactions*** (M&I) curriculum
  - Modernize course content
  - Help improve course outcomes

Matter & Interactions

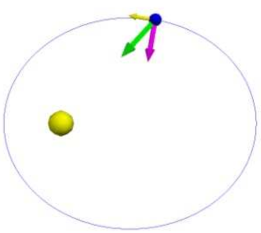
(R. Chabay & B. Sherwood, Wiley, 2007)

- Fundamental principles
- Microscopic structure of matter
- Coherent framework (including 20th century physics)
- Computer modeling
  - VPython: Programming language that easily allows for 3D graphics
  - Students model a wide variety of different systems

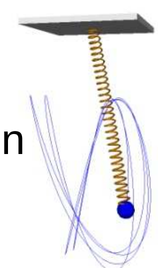




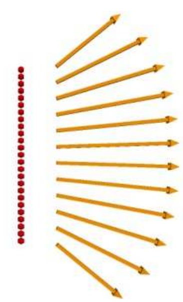
Orbital motion



Mass on spring



Visualizing E&M fields



Implementation

- Gradual ramp up
- Summer 06:
  - 1 pilot section of 1st semester mechanics, 40 students
- Fall 08:
  - 2 sections of M&I mech. (300 students total)
  - 3 sections of M&I E&M (450 students total)
  - *Nearly half* of the total intro enrollment
- Increase in faculty adoption
  - Apprenticeship, co-teaching
- M&I popular with students
  - Courses well-subscribed, fill quickly

Assessment

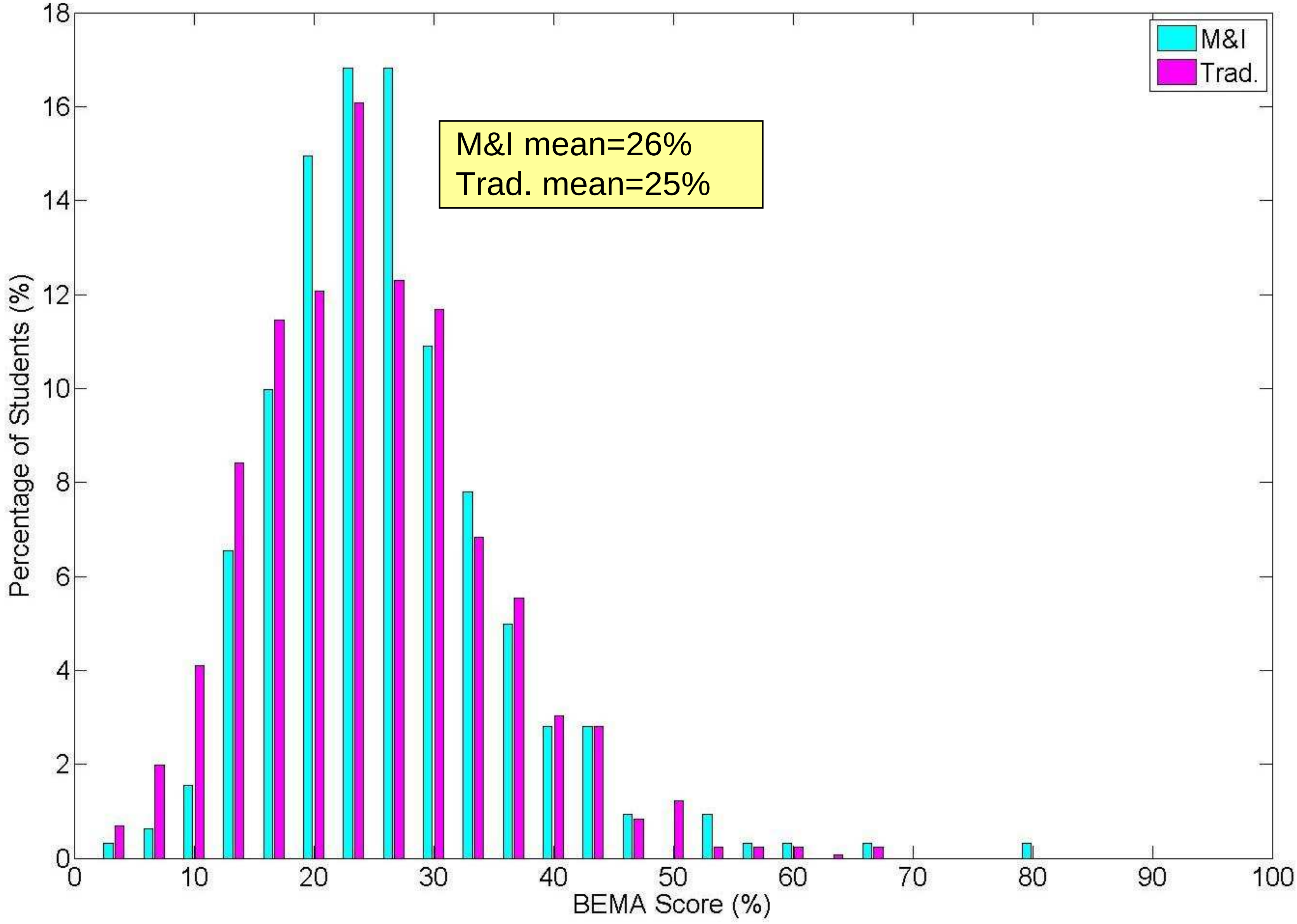
- Compare student performance: M&I vs. traditional course
- Focused mostly on overlap of content between M&I and traditional
- Methods:
  - Standardized tests ← Focus on E&M
  - Common exam problems
  - Interview study

Assessing E&M courses

- Brief E&M Assessment (BEMA)
  - Standardized test
  - Multiple choice
  - 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

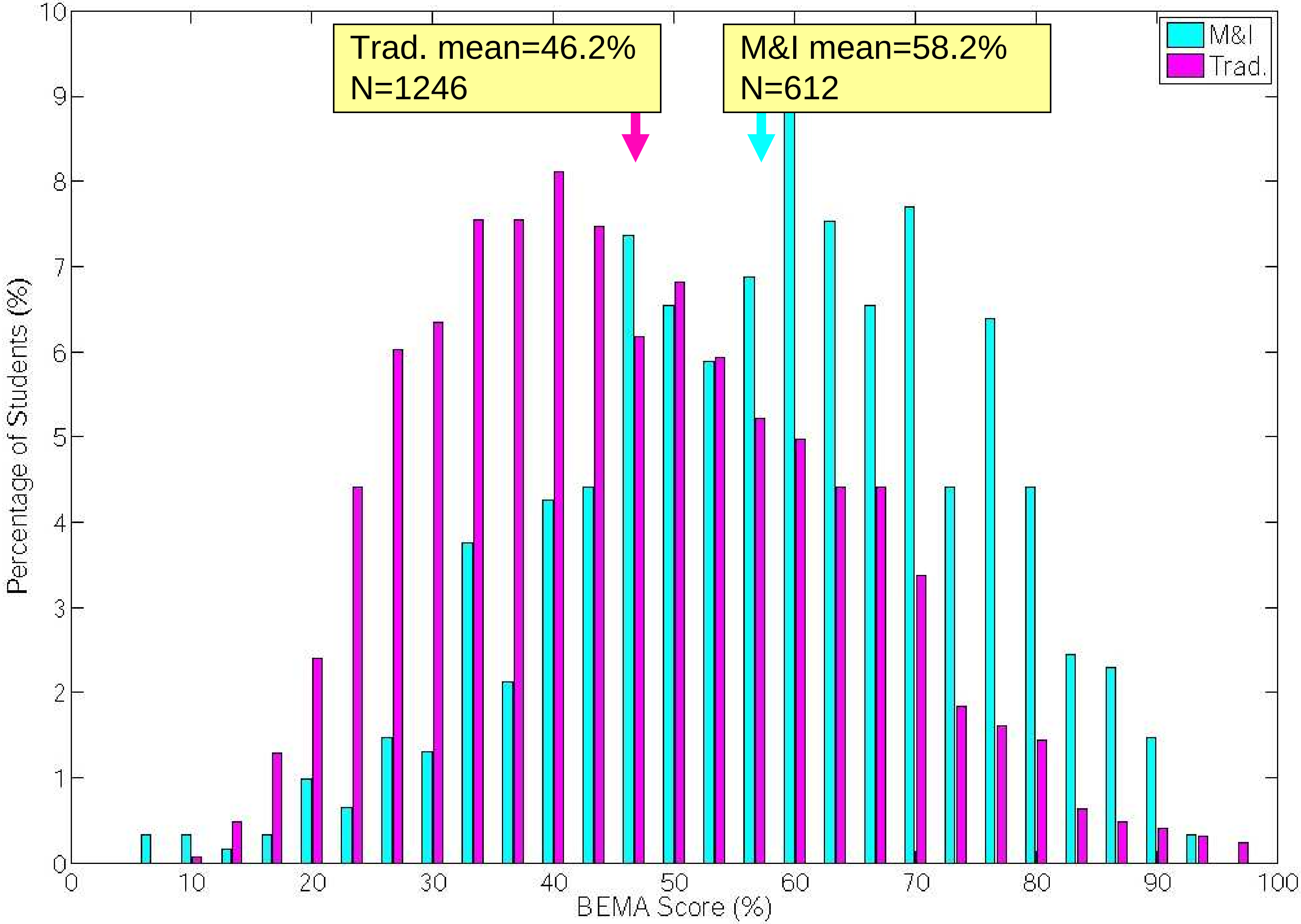
BEMA Pre-test results

Multiple lecture sections from Fall 06 to Fall 07

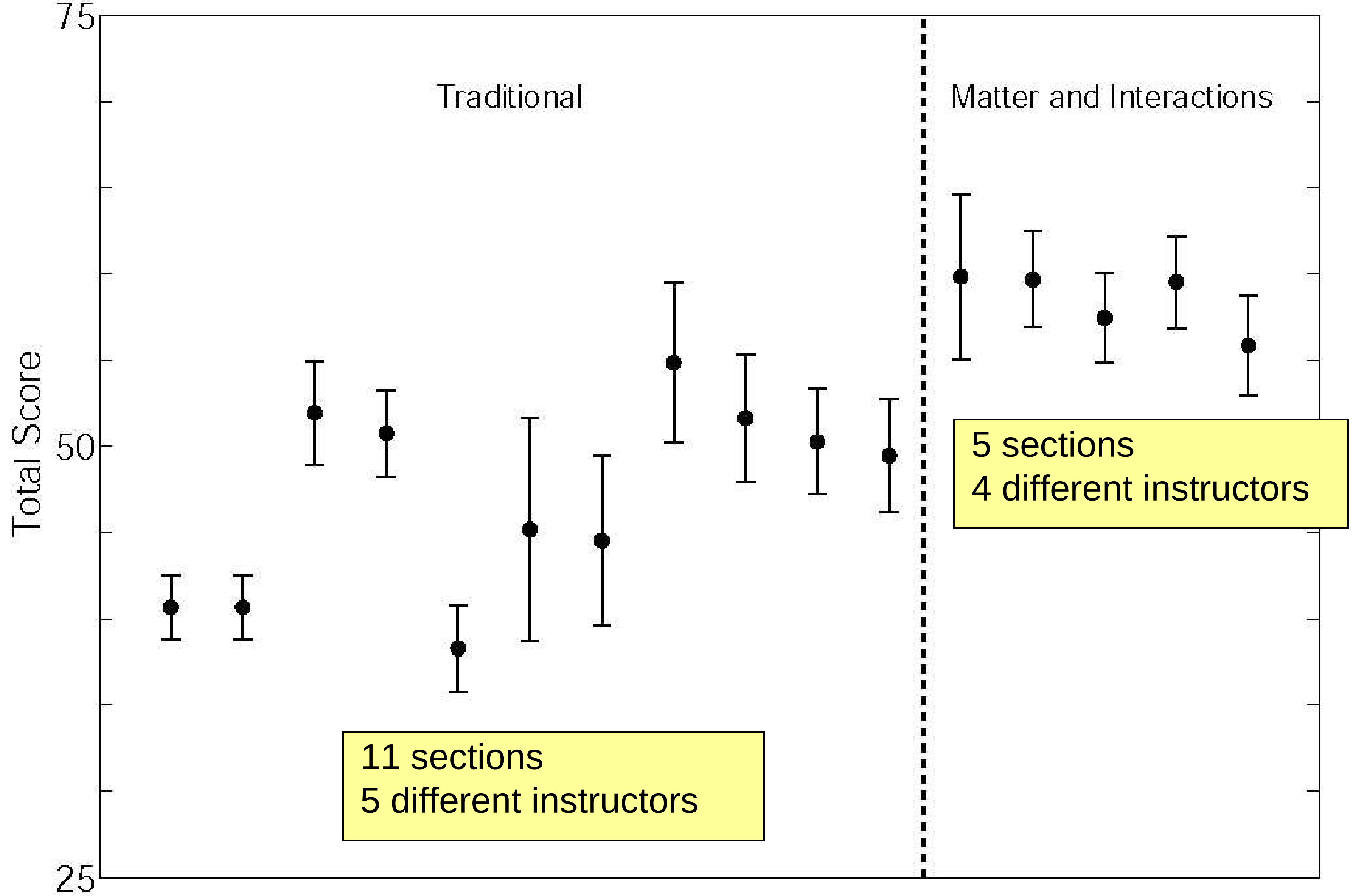


BEMA Post-test results

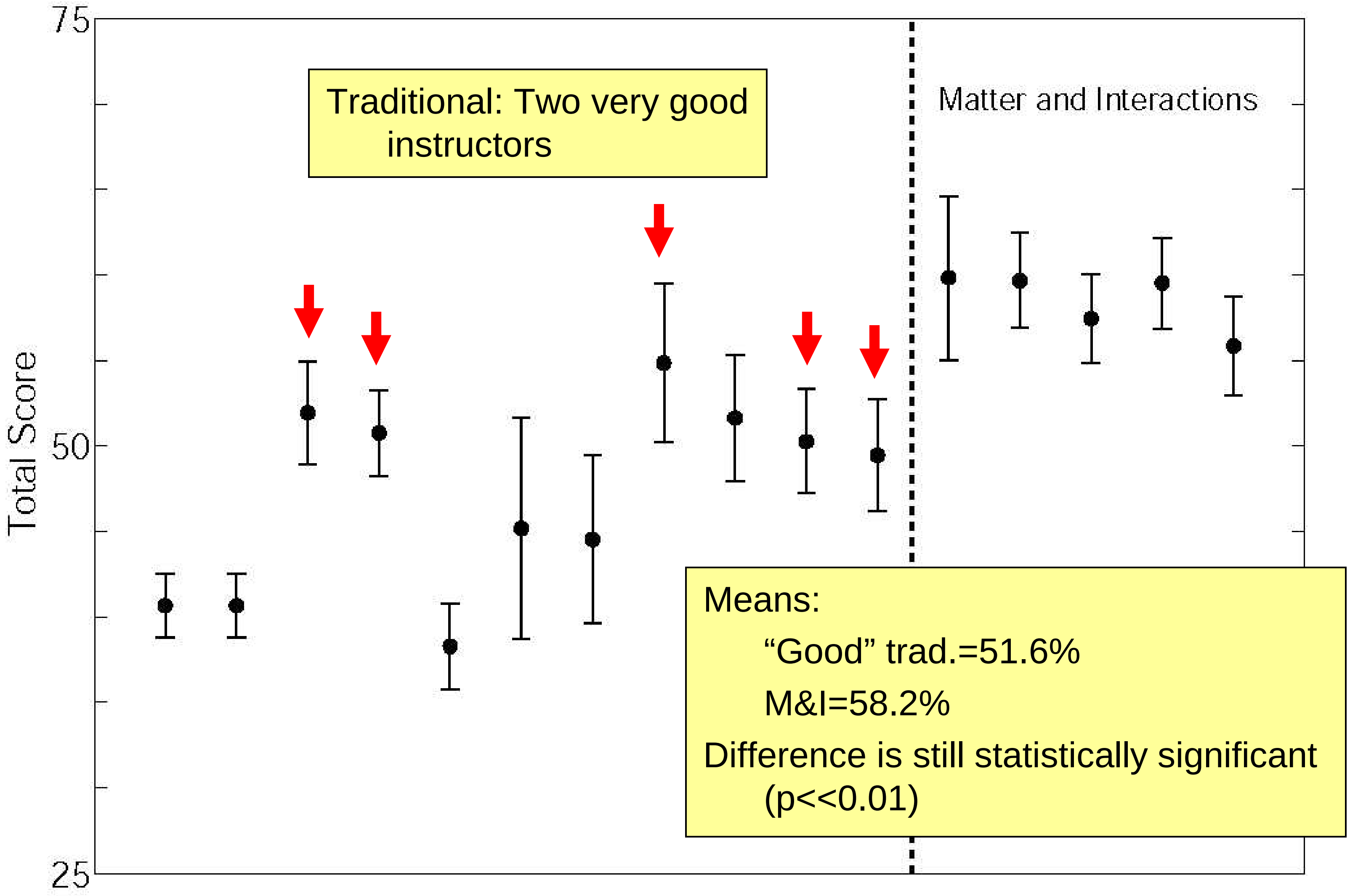
Multiple lecture sections from Fall 06 to Fall 07



BEMA: Post-test results by section



BEMA: Post-test results by section



Assessing mechanics

- More complex task
  - Less overlap between M&I and traditional course content than E&M: what is a fair comparison?
- M&I: lower gains on standardized assessment
  - Assessment emphasizes more traditional problem types
  - M&I students may need more practice applying fundamental principles to these systems
- Assessing M&I specific content
  - Substantial gains on M&I specific energy assessment
  - Complex problems

Summary

- E&M
  - M&I outperforming traditional course in student understanding of basic E&M topics
- Mechanics
  - Complexity in making direct comparisons
  - More work is needed to shore up M&I students' understanding of more traditional topics
- Future assessment
  - "Think aloud" protocol study: examine in more detail student reasoning on
  - Broader impact: effect on future coursework, complex problem-solving skills

Acknowledgments

- Danny Caballero, GT School of Physics
- Keith Bujak, GT School of Psychology
- Collaborators at NC State, Purdue

Common exam problems

- Several common final exam problems have been given to both M&I and traditional courses
- Mechanics: M&I and traditional classes perform on par
  - Note that common questions have been biased toward more traditional material to be fair to traditional course
- E&M: M&I shows better performance on complex problems (e.g. Faraday's Law of Induction problem)
  - Note M&I and trad. E&M have more overlap in classes of problems covered

Force Concept Inventory

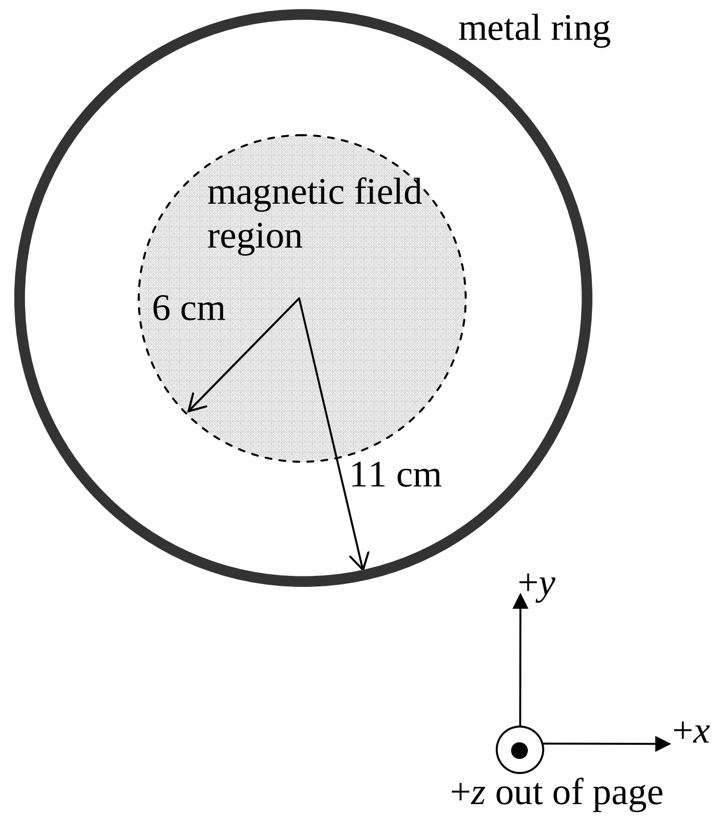
- FCI gains for M&I course are *worse* than for traditional course
  - Normalized gain: Fraction of possible gain from pre to post:
    g = (post% - pre%) / (100% - pre%)
  - Traditional course at Georgia Tech: <g> ranges from 0.35 to 0.5
  - M&I course: <g> about 0.2
- Possible reasons
  - FCI: places emphasis on 2-D constant acceleration kinematics
  - M&I: more emphasis on impulse and momentum, less on acceleration
- Possible solution—implication for instruction
  - Include more examples of applying fundamental principles in more traditional problems

Implementation

- Faculty adoption
  - Different course content and structure: potential barrier
  - Apprenticeship model
    - Several new faculty members were convinced to try M&I
    - Worked closely with veterans
    - Summer 07: Co-taught M&I E&M with veteran faculty member
  - Reactions from faculty new to M&I have been very positive
  - By the end of Fall 2008, the GT School of Physics will have 6 faculty experienced in *M&I*

Common final exam problem: traditional and M&I E&M courses, Spring 07.

A uniform magnetic field is present in a circular region of radius 6 cm. In this region at any given time, the magnetic field may be pointing directly out of the page (in the +z direction), directly into the page (in the –z direction), or it may be zero. The z-component of the magnetic field in this region changes with time according to the function $B_z = Kt^2 - P$, where t is time, $K = 0.12\ \mathrm{T/s^2}$, and $P = 3.0$ T. Outside of the 6 cm radius, the magnetic field is always zero. A thin metal ring of radius 11 cm is concentric with the region of magnetic field. The ring has a resistance of 1.3 x 10–3 Ω.



(a) At time t = 3 s, find the magnitude of the induced current in the metal ring.

(b) At time t = 3 s, find the direction of the induced current in the metal ring (clockwise, counter-clockwise, or zero), and briefly explain your reasoning.

Common E&M final exam problem, Spring 07	**Trad. EM sec.** **N=157**	**M&I EM sec.** **N=152**
Completely correct (magnitude & direction)	17%	28%
Used **correct approach** to find magnitude (w/ possible minor errors)	32%	51%
Used **wrong principle** to find magnitude	43%	15%
Correct direction w/ correct reasoning	36%	57%

Setup

3D graphics

Create objects, give initial pos.

Constants

Initial momentum

Timestep
Reset time

```
from visual import *

planet=sphere(pos=(0,0,0),radius=3e7,
              color=color.green)
moon=sphere(pos=(3.84e8,0,0),radius=2e7,
            color=color.blue)
moon.trail=curve(color=moon.color)

planet.m=6e24
moon.m=7.4e22
G=6.67e-11

speed=2*pi*4e8/(29*24*3600)
moon.p=moon.m*vector(0,speed,0)

deltat=2.5e3
t=0
```

Physics loop

```
while t<28*24*60*60:

    r=planet.pos-moon.pos
    rmag=sqrt(r.x**2 + r.y**2 + r.z**2)
    rhat=r/rmag

    Fmag=G*moon.m*planet.m/rmag**2
    F=Fmag*rhat

    moon.p=moon.p+F*deltat
    moon.pos=moon.pos+moon.p/moon.m*deltat

    moon.trail.append(pos=moon.pos)
    t=t+deltat
```

Rel. pos. vector & unit vector

Grav. force vector

Update p

Update pos.

Draw trail

Update time

“Think-aloud” protocol study

- Ongoing project: to examine in more detail why M&I students have difficulty with FCI
- Volunteers from M&I and traditional courses work on FCI problems in an individual interview setting while saying out loud what comes to mind
- Data collected, currently being analyzed