A Computerized Problem Solving Laboratory for Introductory Physics

Pat Heller, Charles Henderson, Vince Kuo
Department of Curriculum and Instruction
University of Minnesota

Ken Heller
School of Physics and Astronomy
University of Minnesota

Details at http://www.spa.umn.edu/groups/phyled/

Supported in part by NSF, and the University of Minnesota

Thanks to University of San Diego
1. Write down 3 things that you want to get out of this workshop.
2. In groups of 3 introduce yourselves (your field, what you teach, ...), compare lists and decide on the one most important thing you want to get out of this workshop.

**TIME ALLOTTED**
2 minutes for individual list, 5 minutes for group list.

**PROCEDURES**
*Formulate* a response individually.
*Discuss* your response with your partners.
*Listen* to your partners' responses.
*Create* a new group response through discussion.
AGENDA
A Guide for Discussion

1. Problem Solving (≈ 1/2 hour)
   - Why emphasize problem solving?
   - What is problem solving?

2. Problem Solving Laboratory (≈ 1 hour)
   - Principles
   - Example - Magnetic Field
   - Discussion

3. Computers in the Laboratory (≈ 1/2 hour)
   - Principles
   - Execution
4 Motion Data with Video (≈ 1 hour)
- How to do it - a demonstration
- Analysis of a video
- Discussion

5 Optimal Apparatus (≈ 1/2 hour)
- Magnetism
- Forces
- Discussion

6 Assessment (≈ 1/2 hour)
- Students - Lab reports
- Course

7 Concluding Discussion
What Do Departments Want?

**Goals:** Calculus-based Course (88% engineering majors)

- 4.5 Basic principles behind all physics
- 4.5 General qualitative problem solving skills
- 4.4 General quantitative problem solving skills
- 4.2 **Apply physics topics covered to new situations**
- 4.2 Use with confidence

**Goals:** Algebra-based Course (24 different majors)

- 4.7 Basic principles behind all physics
- 4.2 General qualitative problem solving skills
- 4.2 **Overcome misconceptions about physical world**
- 4.0 General quantitative problem solving skills
- 4.0 Apply physics topics covered to new
What Is Problem Solving?

◆ “Process of Moving Toward a Goal When Path is Uncertain”
  ▼ If you know how to do it, its not a problem.
  ▼ A problem for your student is not a problem for you
  ● Exercise vs Problem

◆ Problems are solved using tools
  General Purpose Heuristics
  Not algorithms

◆ Problem Solving Involves Uncertainty and Mistakes

M. Martinez, Phi Beta Kappan, April, 1998
Some Heuristics

Means - Ends Analysis
identifying goals and subgoals

Working Backwards
step by step planning from desired result

Successive Approximations
range of applicability and evaluation

External Representations
pictures, diagrams, mathematics

General Principles of Physics
Teaching Students to Solve Problems

Solving Problems Requires Conceptual Knowledge:

From Situations to Decisions

- Visualize situation
- Determine goal
- Choose relevant information
- Choose applicable principles
- Construct a plan
- Arrive at an answer
- Evaluate the solution

Students must be taught explicitly

The difficulty -- major misconceptions, no heuristics, lack of metacognitive skills
Metacognitive Skills

- Managing time and direction
- Determining next step
- Monitoring understanding
- Asking skeptical questions
- Reflecting on own learning process
Explicit Problem-solving Framework
Used by experts in all fields

**STEP 1**
Recognize the Problem
What's going on?

**STEP 2**
Describe the problem in terms of the field
What does this have to do with ...... ?

**STEP 3**
Plan a solution
How do I get out of this?

**STEP 4**
Execute the plan
Let's get an answer

**STEP 4**
Evaluate the solution
Can this be true?
Why Labs?

Laboratory environment can help students:

- visualize physical situations
- learn to talk physics in a “natural” situation
- connect physics to reality
- develop their physical intuition
- create necessary disequilibrium

Qualitative feedback (written lab reports): Uncovers “misknowledge”

Extended time for coaching (peer & TA): Cooperative Groups

Accommodates diversity of pace & style: Guided “self-paced”
Why Not Labs

✱ Expensive

✱ Time consuming for students

✱ Faculty don’t pay attention to them
  ● Student activity is enough
  ● TA’s can monitor them

✱ TA’ don’t like them
  ● Not “teaching” (lecturing)

✱ Students don’t like them
  ● Waste of time
Traditional Laboratories Do Not Work

- Disconnected from lecture
- Different goals from lecture
- No modeling requires either
  - Cookbook
  - Discovery
  Neither effective for learning physics

Use Laboratory for Coaching (Modeling in Lecture)

Students work on an appropriate task
- In small groups (peer coaching)
- Intervention by instructor (expert coaching)

Need
- Appropriate task
- Group structure
- Intervention tactics
A Systematic Approach to Instructional Design

Transformation Process

Initial State of Learner

Curriculum & Instruction

Desired Final State of Learner

Ladders

Barriers

F. Reif (1986)
*Phys. Today* 39
Zeroth Law: If you don't grade for it, students won't do it.

1st Law: Doing something once is not enough.
2nd Law: Don't change course in midstream!
3rd Law: Make it easier for students to do what you want them to do and difficult to do what you don’t want.

GOAL: Learn Physics Through Problem Solving

Plug and chug

Pattern-Matching
Goals for Problem-solving Labs
Same as the Goals for the Course

Know the *basic principles* of physics.

**Solve problems** using general *qualitative* logical reasoning and *quantitative* problem-solving skills within the context of physics.

**Apply** the physics topics covered to *new situations* not explicitly taught by the course.
Problem Solving Laboratories

- Closely integrated with lecture & recitation
- Always context-rich problems
- Emphasize modeling real systems
- Embody misconceptions
- Use problem solving strategy
- Work in Cooperative Groups
Laboratory Design
Guiding Principles

◆ **Connection** between the physics and the apparatus must be **simple and direct** to the students.

◆ Correct physics predictions must **agree** with simple measurements to **within 10%**.

◆ Equipment must be simple enough for students to manipulate with **minimal instructions**.

◆ **Minimize** the amount of **equipment** used in the course

  *(New Physics ≠ New Equipment)*
  
  ◆ Equipment must be **robust**.
  ◆ Equipment **available** for more than one week.
A “Lab” lasts 2 - 3 weeks, and consists of several related problems in a topic area.

Each problem takes 1 - 2 hours to complete in a lab session.

There are more problems than the typical group can complete in the time allotted

- teaching team choose a preferred order and minimum number of problems to match the emphasis of the lectures;

- instructor can select additional problems to meet the needs of individual groups.

Theory is given only in the text to emphasize that the lab is an integral part of the course.
Teaching Problem Solving Labs

Preparation

Group Predictions

Class Discussion

Measurement & Analysis

Closing Discussion
Prelab Computer Checkout

Designed to make sure students have read relevant text material before they come to lab.


2. Students can take as many times as they wish, using textbook, notes, and other students.

3. Computer randomly changes question order, numbers and vector orientations in questions.

4. Questions require minimal understanding of concepts.
   - about 4 questions (multiple choice, numbers with units, or drawings).
   - if student misses a question, test expanded to give student another chance at similar question.
   - 70% to pass.
Consider the acceleration of the ball. On the graph, place an arrow at a point where the magnitude of the acceleration of the ball was seen. Click on the OK button when you are satisfied with the location of your arrow.

- **amplitude** = 22 cm
- **angular frequency** = 2.53/s
- **mass** = 0.21 kg
Lab Prep Quiz

Oscillations

This graph represents the motion of an object undergoing simple harmonic motion.

Position of Object (centimeters)

Clock Reading (seconds)

Which of the graphs below represents the velocity of the object?

Click on the button under the graph you believe is correct.

A

B

C

D
You have been hired as part of a team to design new port facilities for Duluth. Your assignment is to evaluate a new crane for lifting containers from the hold of a ship. The crane is a boom (a steel bar of uniform thickness) with one end attached to the ground by a hinge that allows it to rotate in the vertical plane. Near the other end of the boom is a motor driven cable that lifts a container straight up at a constant speed. The boom is supported at an angle to the horizontal by another cable. One end of the support cable is attached to the boom and goes horizontally to a pulley. The other end goes over a pulley and is attached to a counterweight that hangs straight down.
The pulley is supported by a mechanism that adjusts its height so the support cable is always horizontal. Your task is to determine how the angle of the boom to the horizontal changes as a function of the weight of the container being lifted. The mass of the boom, the mass of the counterweight, the attachment point of the support cable, and the attachment point of the lifting cable have all been specified by the engineers.

How does the angle of the boom to the horizontal depend on the weight to be lifted?

You decide to solve this problem with a laboratory model of a crane.
You will have a bar, a pulley, some string, and two objects (A and B) of different mass.

Prediction

Calculate the angle of the bar from the horizontal as a function of the weight of object A (with everything else fixed.)

Make a graph of the bar’s angle as a function of the weight of object A.
Methods Questions (Coaching Problem Solving)

To complete your prediction, apply a problem-solving strategy.

1. Make a sketch of the situation (similar to the diagram in the Equipment section). Identify and label the known (measurable) and unknown quantities. On your sketch, show the direction of all relevant forces and accelerations.

2. What object(s) are of interest to you? Describe their motion? What principle(s) of physics relates the forces on each object to its motion?

3. Draw a free body diagram of each object of interest. Label all forces. Determine a useful coordinate system. Write down the equations determined by each diagram. Does any equation contain your target quantity?
Collect the necessary parts of your crane. Find a convenient place to build it.

Decide on the easiest way to determine where the center of mass is located on the bar.

Determine where to attach the lifting cable and the support cable so that the crane is in equilibrium for the weights you want to hang. Try several possibilities. If your crane tends to lean to one side or the other, try putting a vertical rod near the end of the crane to keep it from moving in that direction. If you do this, what effect will this vertical rod have on your calculations?

Do you think that the length of the strings for the hanging weights will affect the balance of the crane? Why or why not?

Outline your measurement plan.
Measurement

Make all necessary measurements of the configuration. Change the mass of object A and determine the angle of the bar when the system is in equilibrium. Remember to adjust the height of the pulley to keep the support string horizontal.

Is there another configuration of the three objects that also results in a stable configuration?

Analysis

Make a graph of the bar’s angle as a function of the weight of object A. What happens to that graph if you change the mass of object B? The position of the attachment of the support cable to the bar?
Did your crane balance as designed?

What corrections did you need to make to get it to balance? Were these corrections a result of some systematic error, or was there a mistake in your prediction?

In your opinion, what is the best way to construct a crane that will allow you to quickly adjust the setup so as to meet the demands of carrying various loads? Justify your answer.
Why Computerize Labs?

STUDENT’S NEEDS AND EXPECTATIONS
- computers are already an integral part of technological fields.
- computers are part of their every day world -- they EXPECT the labs to be computerized

PRACTICAL
- computer labs have fewer “pieces” -- easier to maintain, save money in the long run
- computers are an improving technology

IMPROVED LEARNING
- improved visualization
- save time doing repetitive, tedious measurements, so more time to learn physics
What Do We Know About Computerizing Labs?

General Outcomes:

- Traditional labs have no effect on general achievement.
- TIMSS data: classrooms with technology have lower achievement scores
  - technology poorly integrated with content

Physics Labs:

- Carefully designed, well implemented technology in labs can lead to higher achievement scores (e.g. Priscilla Laws, Ron Thornton, Bob Beichner)
- “Teachers must thoroughly integrate software into their instruction and not just tack it on.” (Beichner, AJP, 1996)
Software Rationale

- Use National Instruments (LabVIEW) software to program measurement and analysis tools
  - Can program to match pedagogy for problem solving labs
  - Instructors can make revisions and extensions to change lab problems and pedagogy
  - Can use same software for all computer tools
    - Practice Fit, Video analysis, Hall Probe, Oscilloscope
  - Software available and updated to match new processors and operating systems
**Choices**

**Mechanics - Video for motion measurements**
- More direct connection to reality for students
- More versatile - one technique to do all measurements
  - 1 D and 2 D motion
  - Linear and Rotations
- Technology will improve - driven by industry

**Electricity and Magnetism - Vernier ULI interface**
- Reasonably inexpensive
- Software controls are public to allow program changes by instructor
3rd Law: Make it easier for students to do what you want them to do and difficult to do what you don’t want.

It should be impossible (very difficult) to make progress
  • If students don’t know what they are doing and why
  • If students don’t understand the physics

It should be easy to make measurements and do analysis
  • If students know what they are doing and why
  • If students understand the physics
User Interface

Make a prediction of the object's motion along the X-axis. Select an equation and variables to match the motion along the horizontal axis. Select "Accept X Prediction" when satisfied.

Guide Box
Predicted Graph

\[ u(t) = A + Bt \]

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>Fit Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.500</td>
<td>B</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>0.000</td>
<td>D X Prediction</td>
</tr>
</tbody>
</table>

\[ u(t) = A + Bt + Ct^2 \]
\[ u(t) = A + Bt + Ct^2 + Dt^3 \]
\[ u(t) = A + B \sin(Ct + D) \]
\[ u(t) = A + B \cos(Ct + D) \]
\[ u(t) = A + B \exp(-Ct) \]
\[ u(t) = A + B\{1 - \exp(-Ct)\} \]
Graphing Data
Fitting Data to Equation

\[ u(t) = A + Bt \]

\[ u(t) = A + Bt + Ct^2 \]

\[ u(t) = A + Bt + Ct^2 + Dt^3 \]

\[ u(t) = A + B \sin(Ct + D) \]

\[ u(t) = A + B \cos(Ct + D) \]

\[ u(t) = A + B e^{Ct} \]

\[ u(t) = A + B \{1 - e^{-Ct}\} \]
Optimal Apparatus - Magnetism

One Apparatus for the entire topic of magnetism

\(~ 5 \text{ out of 15 weeks of course time}\)

\(\triangledown \) 3 chapters from the textbook
   - magnetic fields
   - magnetic fields due to current induction and inductance

\(\triangledown \) Context rich” laboratory problems
   - 8 on fields and forces
   - 6 on flux and induction
Design Criteria

▼ Pedagogical - easy to understand and multipurpose
  ● problem solving
  ● physics principles

▼ Practical - efficient and robust
  ● extensive usage
  ● lack of maintenance time
Standard Set-up
Fields

Biot-Savart

- Measure magnetic field due to current in one or two coils
Forces

\[ F = qv \times B \]

- Measure deflection of electron beam due to magnetic field
• Measure angular dependence of magnetic field measured by hall probe (or pick-up coil).
Induction

\[ \varepsilon = -\frac{d\Phi}{dt} \]

- Rotating pick-up coil with steady current in Helmholtz coils
- Stationary pick-up coil with time-varying current in Helmholtz coils.
Design Features

① Easy viewing and access to all parts
② Holes accommodate CRT
③ Easy removal and addition of rotating pick-up coil and motor
Design Features

- Electrical Contact
- Mercury Lubricated Bearings
- Extremely Stable Mounting
Summary

◆ Uses for the apparatus

* Magnetic fields of current carrying wires
  - single coil
  - two parallel coils

* Magnetic forces on a moving charge
  - deflection of electron beam in constant field

* Magnetic flux
  - angular dependence

* Magnetic induction
  - rotating coil in constant field
  - stationary coil in time-varying field
One Apparatus probes many student difficulties

- **Vector Nature**
  - Independence of perpendicular components
  - Use of trigonometry necessary

- **Relationship to physical objects**
  - Forces act on objects
  - Direction of forces to connection of objects

- **Forces without motion**

Determine d as a function of m, M, L
How Do Labs Fit In?

LECTURES

Three hours each week, sometimes with informal cooperative groups. Model constructing knowledge, model problem solving strategy.

RECITATION SECTION

One hour each Thursday -- groups practice using problem-solving strategy to solve context-rich problems. Peer coaching, TA coaching.

LABORATORY

Two hours each week -- same groups practice using strategy to solve concrete experimental problems. Same TA. Peer coaching, TA coaching.

TESTS

Friday -- problem-solving quiz & conceptual questions (usually multiple choice) every two weeks.
The Course as a System

Use strengths of components acting together

Lectures (150 - 300 students)
- Model construction of knowledge
  - Explicit Storyline
  - Motivate all concepts

Model problem solving
- A single explicit strategy
- Always start from basic principles

Recitation sections & laboratories (16 students)
- Coach problem solving
  - Same strategy as lecture
  - Same concepts as lecture
UMn MODEL FOR LARGE INTRODUCTORY COURSE

STUDENTS

Modeling
Lecture
Topics
Procedures
Demos
Discussion
Questions
Exams

Coaching
Discussion

Labs

Fading
Outside

Reading
Homework
Predictions
Lab Reports
Studying
Quizzes

Orientation
All TA meetings

Lecturer
TAs
Mentor TA
Student

Problem Solving

Cooperative Groups

Context Rich Problems

Physics Education Research & Development
Grading

1. Instructors grade students’ journals during lab sessions.

<table>
<thead>
<tr>
<th>LABORATORY JOURNAL</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predictions</td>
<td>2</td>
</tr>
<tr>
<td>Lab Procedures</td>
<td>2</td>
</tr>
</tbody>
</table>

2. At end of lab, instructors assign each student one problem to write up (due 2 - 3 days after lab)

<table>
<thead>
<tr>
<th>PROBLEM REPORT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Organization</td>
<td>2</td>
</tr>
<tr>
<td>Data and Data Tables</td>
<td>2</td>
</tr>
<tr>
<td>Results</td>
<td>2</td>
</tr>
<tr>
<td>Conclusions</td>
<td>2</td>
</tr>
</tbody>
</table>

Total 12
Bonus Points 2
Formative Evaluation

- Lab Reports
- Concept Tests
- Student Questionnaires
- Observations of Labs
- Interviews of TAs
- TA questionnaires
Lab Reports

Analyzed based on 5 criteria from literature on technical communication in writing

Pilot Study

One class of 15 students
11 of which had all 6 laboratory reports from the entire 15-week semester (n = 11)

Each student is placed into one of three groups based on the grade of the first report

Poor
# Guideline for grading laboratory reports

**For Students and TAs**

<table>
<thead>
<tr>
<th>Problem Report:</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ORGANIZATION</strong></td>
<td></td>
</tr>
<tr>
<td>(clear and readable; correct grammar and spelling; section headings provided; physics stated correctly)</td>
<td></td>
</tr>
<tr>
<td><strong>DATA AND DATA TABLES (GROUP PREDICTIONS)</strong></td>
<td></td>
</tr>
<tr>
<td>(clear and readable; units and assigned uncertainties clearly stated)</td>
<td></td>
</tr>
<tr>
<td><strong>RESULTS</strong></td>
<td></td>
</tr>
<tr>
<td>(results clearly indicated; correct, logical, and well-organized calculations with uncertainties indicated; scales, labels and uncertainties on graphs; physics stated correctly)</td>
<td></td>
</tr>
<tr>
<td><strong>CONCLUSIONS</strong></td>
<td></td>
</tr>
<tr>
<td>(comparison to prediction &amp; theory discussed with physics stated correctly; possible sources of uncertainties identified; attention called to experimental problems)</td>
<td></td>
</tr>
</tbody>
</table>
Laboratory Reports as Communication

Dr. Lee-Ann Kastman Breuch Dept. Of Rhetoric, U of MN

- **Content:** What is the subject? What information needs to be included?
- **Context:** What is expected in the discipline for this type of document?
- **Audience:** To whom is the document written? How will it be used?
- **Organization:** How can the information be best organized? Can the information be divided into sections?
- **Support:** What details, facts, and evidence can be used to illustrate main points?
Example of quality levels - Content

<table>
<thead>
<tr>
<th>Addresses content accurately and thoroughly</th>
<th>Excellent</th>
<th>Good</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Includes accurate and complete technical information, including equations, explanations, theorems, and data.</td>
<td>Includes accurate technical information, but has missed some important information.</td>
<td>Does not include accurate or complete information.</td>
<td></td>
</tr>
</tbody>
</table>

| Score | 3 | 2 | 1 |
Content

All necessary information included
Appropriate structure for a short technical report.
Appropriate level to communicate with introductory physics students.
Logical organization for this material.
Relevant details, facts, and evidence be used to illustrate main points.
Discussion

Students of at all initial levels improved in each of the criteria

- Student groups that initially averaged poor or good reached approximately the same quality by the end of the semester
- Identifiable increases in quality apparent by 3rd or 4th report
  - content, context, audience, & organization
- Slower increases in quality of support (primarily physics)
  - majority of students only slightly higher than “good”
Does Introduction of Computers Lower Student Achievement?

- For 3 of the 5 lecture sections, randomly assigned half of students to computerized labs (N ~ 200 each)
- Extensive TA training, but with minimal focus on computer use -- computer use training as needed
- Continual improvements of software
- Lab problems kept as close as possible to traditional lab problems
<table>
<thead>
<tr>
<th></th>
<th>NO COMPUTERS</th>
<th></th>
<th>COMPUTERS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>% Pretest</td>
<td>47 ± 2</td>
<td>35 ± 2</td>
<td>52 ± 2</td>
<td>32 ± 2</td>
</tr>
<tr>
<td>% Posttest</td>
<td>72 ± 2</td>
<td>61 ± 2</td>
<td>74 ± 2</td>
<td>54 ± 2</td>
</tr>
<tr>
<td>Norm. Gain</td>
<td>49 ± 2</td>
<td>42 ± 3</td>
<td>50 ± 3</td>
<td>34 ± 3</td>
</tr>
</tbody>
</table>
## Test of Understanding Graphs - Kinematics (TUG-K) and Problem-solving Grades (1997)

<table>
<thead>
<tr>
<th></th>
<th>NO COMPUTERS</th>
<th></th>
<th>COMPUTERS</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men (N=122)</td>
<td>Women (N=46)</td>
<td>Men (N=121)</td>
<td>Women (N=49)</td>
</tr>
<tr>
<td><strong>TUG-K</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Pretest</td>
<td>55 ± 2</td>
<td>43 ± 3</td>
<td>62 ± 2</td>
<td>45 ± 3</td>
</tr>
<tr>
<td>% Posttest</td>
<td>74 ± 2</td>
<td>65 ± 3</td>
<td>79 ± 2</td>
<td>64 ± 3</td>
</tr>
<tr>
<td>% Final Probs</td>
<td>53 ± 1</td>
<td>51 ± 2</td>
<td>55 ± 2</td>
<td>51 ± 3</td>
</tr>
</tbody>
</table>
# Survey Results
## 1st-Year Implementation (1997)

<table>
<thead>
<tr>
<th>Survey Statement</th>
<th>NO COMPUTERS (N=168)</th>
<th>COMPUTERS (N=172)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Agree</td>
<td>Neutral</td>
</tr>
<tr>
<td>helped me understand concepts</td>
<td>50</td>
<td>26</td>
</tr>
<tr>
<td>time well-spent learning</td>
<td>38</td>
<td>33</td>
</tr>
<tr>
<td>TA gave useful help when stuck</td>
<td>79</td>
<td>12</td>
</tr>
<tr>
<td>look forward to using . . .</td>
<td>16</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>% Often/A. Always</td>
<td>Often/A. Always</td>
</tr>
<tr>
<td>discuss equipment difficulties</td>
<td>53</td>
<td>32</td>
</tr>
<tr>
<td>discuss physics</td>
<td>39</td>
<td>48</td>
</tr>
<tr>
<td>communicated well</td>
<td>64</td>
<td>67</td>
</tr>
</tbody>
</table>
Second-year Implementation

Planned Changes:
- ALL lecture sections -- 724 students, 31 TAs, 6 lecturers
- More focused TA training on computer use in labs
- Additional information in TA handbook
  - different grouping guidelines for lab, discussion section
  - different seating arrangements
  - what to watch for when monitoring groups
- Mentor TAs knowledgeable about labs

Problems:
- Large scale implementation
- Late delivery of essential equipment
- Increased sizes of lab sections (N~18 students each section)
### FCI Results for Computerized labs

<table>
<thead>
<tr>
<th></th>
<th>1997</th>
<th>1998</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Pretest</td>
<td>52 ± 2</td>
<td>32 ± 2</td>
</tr>
<tr>
<td>% Posttest</td>
<td>74 ± 2</td>
<td>54 ± 2</td>
</tr>
<tr>
<td>Norm. Gain</td>
<td>50 ± 3</td>
<td>34 ± 3</td>
</tr>
</tbody>
</table>
### TUG-K Results for Computerized Labs

<table>
<thead>
<tr>
<th>Year</th>
<th>Men (N=121)</th>
<th>Women (N=49)</th>
<th>Men (N=92)</th>
<th>Women (N=25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Pretest</td>
<td>62 ± 2</td>
<td>45 ± 3</td>
<td>61 ± 2</td>
<td>50 ± 4</td>
</tr>
<tr>
<td>% Posttest</td>
<td>79 ± 2</td>
<td>64 ± 2</td>
<td>74 ± 2</td>
<td>69 ± 4</td>
</tr>
</tbody>
</table>
1. Do you think the lab activities were too easy, too hard, or just about the right level of difficulty?

   too easy  just about right  too hard  
   9%        86%          5%

2. The written instructions in the lab manual were designed to guide your group in making decisions, without explaining how to conduct the lab. Do you think the written instructions provided too much guidance, too little guidance, or just about the right amount of guidance?

   too little  just about right  too much  
   33%        60%           3%
### Student Questionnaire (1992 & 1999)

<table>
<thead>
<tr>
<th></th>
<th>SA</th>
<th>A</th>
<th>N</th>
<th>D</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The laboratory activities were well coordinated with the lecture.</td>
<td>23</td>
<td>64</td>
<td>17</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>43</td>
<td>32</td>
<td>16</td>
<td>2</td>
</tr>
<tr>
<td>2. The laboratory problems helped me to understand the course concepts.</td>
<td>10</td>
<td>64</td>
<td>7</td>
<td>16</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>46</td>
<td>22</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>3. Working with the same group in laboratory and recitation sessions was useful.</td>
<td>16</td>
<td>64</td>
<td>18</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>59</td>
<td>18</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>4. Working with the same materials for at least two weeks helped me to understand the material.</td>
<td>15</td>
<td>64</td>
<td>16</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>54</td>
<td>28</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>5. Comparing our prediction equation to our collected data helped me understand the relationship between our graphs and the observed motion.</td>
<td>11</td>
<td>56</td>
<td>24</td>
<td>6</td>
<td>3</td>
</tr>
</tbody>
</table>

1992 one algebra-based class (n = 135)
1999 four calculus-based classes (n = 450)
Rate the following components of the course using a scale from 1 to 10, with 10 being extremely useful and 1 being completely useless in helping you learn physics in this course.

<table>
<thead>
<tr>
<th>Component</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Textbook</td>
<td>6.6 ± 0.13</td>
</tr>
<tr>
<td>2. CGPS Discussion Sessions</td>
<td>6.5 ± 0.13</td>
</tr>
<tr>
<td>3. Homework (not graded)</td>
<td>6.4 ± 0.14</td>
</tr>
<tr>
<td>4. Lectures</td>
<td>6.1 ± 0.13</td>
</tr>
<tr>
<td>5. Quizzes and Exams</td>
<td>6.1 ± 0.12</td>
</tr>
<tr>
<td>6. Laboratory</td>
<td>5.5 ± 0.12</td>
</tr>
<tr>
<td>7. Material on Class Web Pages</td>
<td>5.3 ± 0.14</td>
</tr>
<tr>
<td>8. TAs in Room 140</td>
<td>4.6 ± 0.14</td>
</tr>
<tr>
<td>9. Tutors in Lind Hall</td>
<td>4.2 ± 0.14</td>
</tr>
<tr>
<td>10. Lecturer’s Office Hours</td>
<td>3.9 ± 0.12</td>
</tr>
</tbody>
</table>
### Survey Results for Computerized labs

<table>
<thead>
<tr>
<th></th>
<th>1997 (N=172)</th>
<th></th>
<th>1998 (N=590)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% Agree</td>
<td>Neutral</td>
<td>% Agree</td>
<td>Neutral</td>
</tr>
<tr>
<td>helped me understand concepts</td>
<td>49</td>
<td>28</td>
<td>55</td>
<td>22</td>
</tr>
<tr>
<td>time well-spent learning</td>
<td>51</td>
<td>30</td>
<td>47</td>
<td>29</td>
</tr>
<tr>
<td>TA gave useful help when stuck</td>
<td>65</td>
<td>16</td>
<td>73</td>
<td>13</td>
</tr>
<tr>
<td>look forward to using . . .</td>
<td>47</td>
<td>33</td>
<td>25</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>% Often/A. Always</td>
<td></td>
<td>Often/A. Always</td>
<td></td>
</tr>
<tr>
<td>discuss equipment difficulties</td>
<td>32</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>discuss physics</td>
<td>48</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>communicated well</td>
<td>67</td>
<td>70</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Several students were hired to observe the introductory calculus-based labs.

- Observed 10 sections for 5 weeks.
- Observers sit in lab by one group with a coding sheet.
- Every minute, observe group, code interactions.
- Many different codes available.
Expected Lab Time

Predictions and discussion (whole-class) 15 min. (~13%)

Start the lab problem:

| Problem 1 | Exploration & Measurement | 15-20 min. (~15%) |
| Problem 2 | Analysis | 10-15 min. (~10%) |
| Problem 2 | Conclusion | 5-10 min. (~6%) |
| Problem 2 | Exploration & Measurement | 15-20 min. (~15%) |
| Problem 2 | Analysis | 10-15 min. (~10%) |
| Problem 2 | Conclusion | 5-10 min. (~6%) |
| Closing discussion | 20 min. (~17%) |

Total Time Spent: 115 min. (100%)
## Observation Codes

<table>
<thead>
<tr>
<th>Code</th>
<th>What it Sounds Like</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social/off-task:</td>
<td>“How did you do on the test?”</td>
</tr>
<tr>
<td>Equipment talk:</td>
<td></td>
</tr>
<tr>
<td>✨ Exploring:</td>
<td>“How does this look?”</td>
</tr>
<tr>
<td>✨ Management:</td>
<td>“Move that over there.” “Go get a cart.”</td>
</tr>
<tr>
<td>Taking data:</td>
<td>“Take a picture now.” “Let the cart go.”</td>
</tr>
<tr>
<td>Analyzing data:</td>
<td>“I think this equation is the right one.”</td>
</tr>
<tr>
<td>Management talk:</td>
<td></td>
</tr>
<tr>
<td>✨ Group:</td>
<td>“Who's writing this down?”</td>
</tr>
<tr>
<td>✨ Task:</td>
<td>“We only have ten minutes left.”</td>
</tr>
<tr>
<td>Talking physics:</td>
<td>“I think that's acceleration, not velocity.”</td>
</tr>
<tr>
<td></td>
<td>“What about friction in our case?”</td>
</tr>
</tbody>
</table>
### Some Results

<table>
<thead>
<tr>
<th></th>
<th>Ideal</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time spent working on problems</strong></td>
<td>80 min</td>
<td>67 min</td>
</tr>
<tr>
<td><strong>Number solved problems</strong></td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>What do groups talk about?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◆ Social Talk</td>
<td>5%</td>
<td>9%</td>
</tr>
<tr>
<td>◆ On task lab talk</td>
<td>95%</td>
<td>91%</td>
</tr>
</tbody>
</table>
How much time do students spend in the different parts of a single problem?
<table>
<thead>
<tr>
<th>Topic</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>18%</td>
</tr>
<tr>
<td>✿ Figuring it out</td>
<td>(11%)</td>
</tr>
<tr>
<td>✿ Working with it</td>
<td>(7%)</td>
</tr>
<tr>
<td>Taking data</td>
<td>10%</td>
</tr>
<tr>
<td>Analyzing data</td>
<td>31%</td>
</tr>
<tr>
<td>Management</td>
<td>15%</td>
</tr>
<tr>
<td>✿ Task management</td>
<td>(15%)</td>
</tr>
<tr>
<td>✿ Group management</td>
<td>(0%)</td>
</tr>
<tr>
<td>Talking to the TA</td>
<td>9%</td>
</tr>
<tr>
<td>Talking physics</td>
<td>6%</td>
</tr>
</tbody>
</table>
Conclusions

- Lab time is spent solving the problem—not talking about the football game
- Too much time is spent on each problem, mostly in analysis
- Little physics talk among the groups
Conclusion

Given a cooperative-group problem solving pedagogy that yields stable, high gains on standardized conceptual tests, the careful implementation of computer measurement and analysis tools in the laboratory did not change student achievement.

NEXT PHASE:

Is it possible to use the new computer tools to target explicit student difficulties, resulting in a higher level of student achievement?