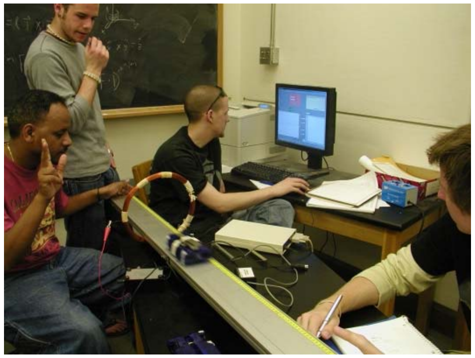
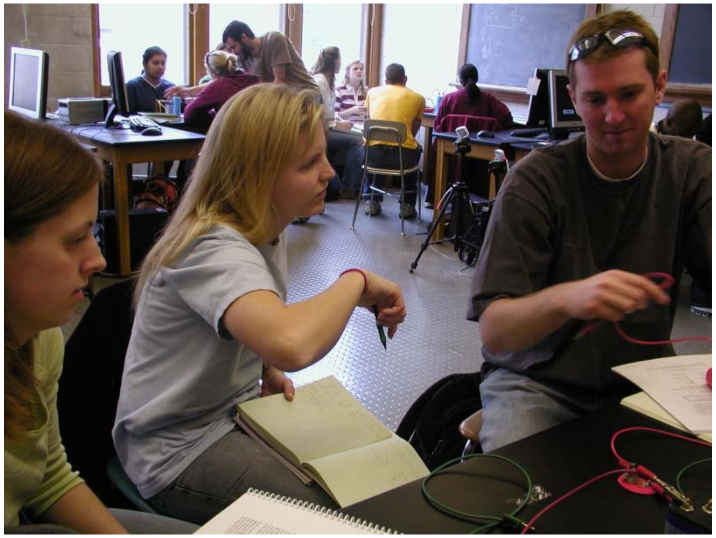
Designing and Implementing a Sustainable Laboratory as Coherent Part of an IPLS Course





Ken Heller

School of Physics and Astronomy

University of Minnesota

Building on a 25 year continuing project to improve undergraduate education by:
Many faculty, graduate students, and staff of U of M Physics Department
In collaboration with U of M Physics Education Group

For more information google: per minnesota

University of Minnesota

Labs as Part of IPLS @ UMN – focus on problem solving

LECTURES

Four hours each week (200 students)
sometimes with informal cooperative groups, peer coaching. Demonstrate building models of biological processes & using a problem solving framework. (4 lecture sections)

DISCUSSION SECTION

One hour each Thursday (18 students)
groups practice using problem-solving framework to solve context-rich problems. Peer coaching, TA coaching.

LABORATORY

Two hours each week (18 students)
same groups practice using framework to solve concrete experimental problems. *Same* TA. Peer coaching, TA coaching.

TESTS

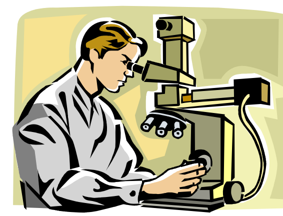
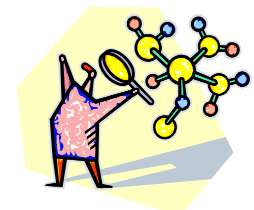
Problem-solving (written) & conceptual questions (multiple choice) every three weeks.
In groups Thursday & individual Friday

Scaffolding – limit formula usage, context rich problems, computer reading tests, clickers, JITT, sample quizzes, problem solving guide, computer coaches

Students in Physics for Biology Majors
600 students/term (class size 150 – 300)

Majors

Biological Science	36%
Pre-Med	31%
Allied Health	18%
Social Science	3%
Kinesiology	2%
Architecture	1%
Agriculture/Ecology	1%
Other	8%

Freshman	7%
Sophomore	38%
Junior	19%
Senior	17%

Male	41%
Female	59%

Pre FCI – 33%

Had U. Calculus	71%
(Had HS Calculus)	50%
Had HS Physics	71%

Expect A	48%
Work	74%
Work more than 10 hrs/wk	50%

Survey of Faculty Likely to Teach Biology Majors After Physics Class

Responding Faculty

N = 20 (60% response)

- **Biochemistry, Molecular Biology and Biophysics (5)**
- **General Biology (1)**
- **Genetics, Cell Biology and Development (3)**
- **Ecology, Evolution and Behavior (2)**
- **Microbiology (3)**
- **Neuroscience (3)**
- **Plant Biology (3)**

In what year should your students take physics?

	Freshman	Sophomore	Junior	Senior
%	20	75	5	0

How many semesters of physics do you think should be required for your students?

	0	1	2	3	4	5	6
%	0	15	75	0	0	0	0

Faculty Free Responses - Goals

1. In your opinion, what is the primary reason your department requires students to take this physics course?

Underlying Principles | Application | Problem solving/math

- To understand the basic laws of physics; to be able to apply physical principles to other problems; to overcome fear of math, quantitative approach to science.
- General understanding of how 1st & 2nd order linear differential equations explain behavior of various physical systems (mechanics, thermodynamics, electricity).
- Living things rely on a number of physical principles. Concepts we cover in lecture & techniques/equipment used in the laboratory require an understanding of physics. Physics is fundamental to many biological processes, & develop skills in problem-solving & modeling.
- Provide basic concepts in physics as applied to biological functions; learn how to think quantitatively about these applied physics concepts.

What Should Students Learn From The Physics Course?

1 = unimportant	2 = slightly important	3 = somewhat important	4 = important	5 = very important

Goals for biology students taking physics rated > 4

- 4.9 Basic principles behind all physics
- 4.3 General qualitative problem solving skills
- 4.3 Use biological examples of physical principles
- 4.1 General quantitative problem solving skills

Highest rated goals in more detail (most important + forced choice)

Goal	4 & 5 %	* %	average
Know the basic principles behind all physics (e.g. forces, conservation of energy, ...)	100	35	4.8
Know the range of applicability of the principles of physics (e.g. conservation of energy applied to fluid flow, heat transfer, …)	87	9	4.0
Solve problems using general qualitative logical reasoning within the context of physics	83	9	4.3
Solve problems using general quantitative problem solving skills within the context of physics	82	22	4.1
Provide biological examples of physical principles within the context of physics	78	35	4.3
Provide real world applications of mathematical concepts and techniques within the context of physics	74	0	4.0
Overcome misconceptions about the behavior of the physical world	69	17	4.0
Analyze data from physical measurements	69	0	3.9

1 = unimportant	2 = slightly important	3 = somewhat important	4 = important	5 = very important

Please place a star (*) next to the TWO goals listed above that you consider to be the MOST IMPORTANT for your students.

Lower rated goals — Goal	4 & 5 %	* %	average
Apply the physics topics covered to new situations not explicitly taught by the course	57	9	3.4
Use modern measurement tools for physical measurements (e.g. spectrophotometers, computer data acquisition, timing techniques,...)	56	4	3.7
Use with confidence the physics topics covered	56	0	3.6
Express, verbally and in writing, logical, qualitative thought in the context of physics	52	0	3.4
Use computers to solve problems within the context of physics	44	0	3.1
Be familiar with a wide range of physics topics (e.g. specific heat, AC circuits, rotational motion, geometrical optics, fluids, relativity, …)	39	13	3.4
Formulate and carry out experiments	39	0	3.3
Understand and appreciate 'modern physics' (e.g. nuclear decay, quantum optics, cosmology, quantum mechanics, elementary particles,...)	22	0	3.0
Understand and appreciate the historical development and intellectual organization of physics	17	0	2.7
Prepare students for the MCAT	13	0	2.4
Other goal. Please specify.	9	0	

Physics teaching lab skills not a high priority

Other goals

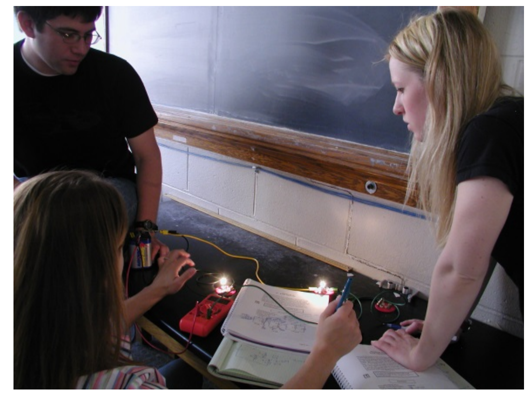
5: Provide examples of physics within a biological context.

5: Conceptual thinking. Seeing a big picture rather then only memorizing facts.

Why Have Labs?

Laboratory environment can help students:

- **visualize physical situations**
- **learn to talk physics in a "natural" situation**
- **experience building simple testable models**
- **connect physics to reality**
- **develop physical intuition**
- **deal with ambiguity**
- **create necessary disequilibrium**

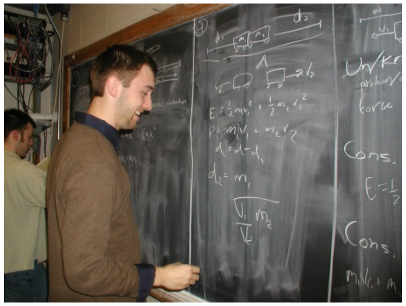


Extended time for coaching (peer & TA):
Cooperative Groups

Accommodate diversity of pace, style, & emphasis:
Guided "self-paced"

Detailed feedback (written lab reports):
Uncovers "misknowledge"

Student Actions in a Problem Solving Lab



Individual preparation

Pass reading quiz
(3 out of 4 basic questions)

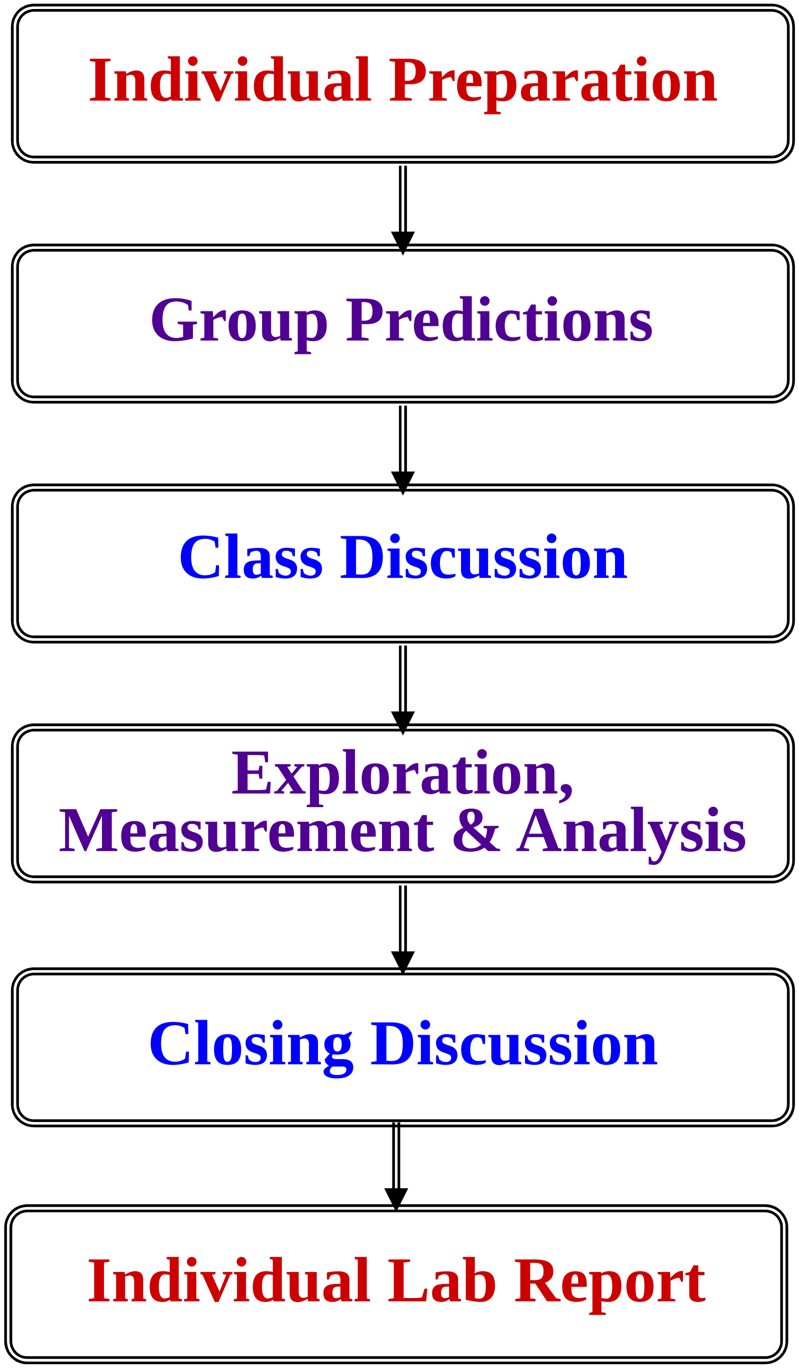
Make a good effort on warm up questions and prediction. Not graded for correctness.

TA sees these before lab to help guide their coaching

Individual lab reports

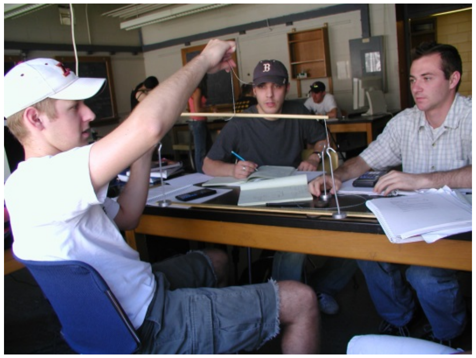
Short technical report - < 5 pages
After ~3 weeks of labs (one topic)

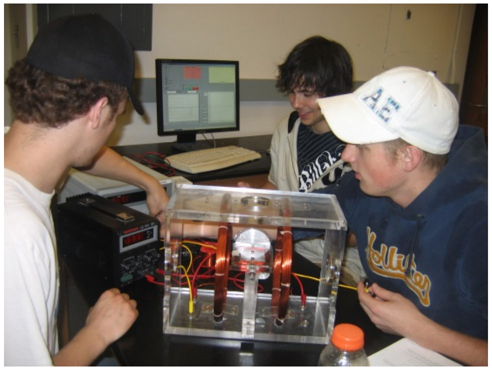
Learning integration
Importance of lab journal



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 session.**





Solving problems requires applying conceptual understanding to unfamiliar situations

Ideally, no progress without understanding the underlying physics

Need for coaching intervention is obvious

All elements of the class are synchronized to within a week

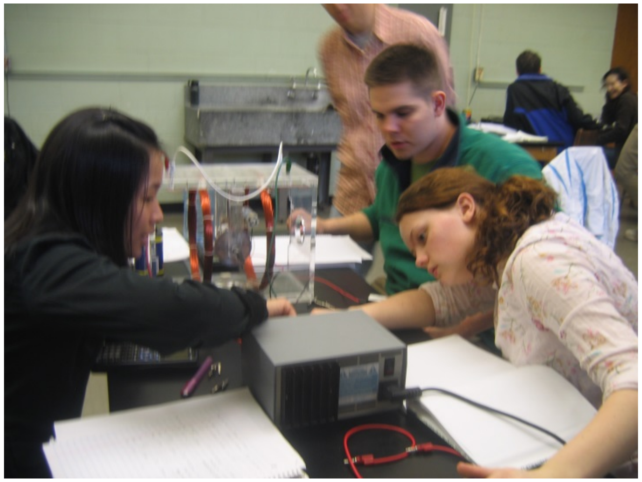
Lab problems look like test problems

Same type of problems in lecture and discussion sections

Problem solving lab - approximately 2 lab problems/2hr period

Lab Instructions

- Problem statement
- General equipment description
- Warm-up questions
- Make a Prediction
- Explore the Equipment
- Make the Measurements
- Do the Analysis
- Draw a Conclusion



Problem Solving Lab: Problem Statement

Making & Testing Simple Models

You are studying how bacteria migrate through the body. You know that when single-cell organisms such as bacteria move, the medium through which they move plays an important role. When it begins to move, the organism quickly reaches a terminal velocity, after which it must constantly expend energy to continue at the same velocity. As a first step to understanding the approach to terminal velocity, you decide to model the organism as a spherical bead falling through a liquid. You calculate the velocity of a bead as a function of time, the properties of the bead and the properties of the fluid.

Read Sternheim & Kane: Chapters 1, 3, 13.1, 14.5, 14.6.

Context rich problem

Vague enough so that each student can fill in the details from their own knowledge

EQUIPMENT

For this problem you have clear cylinders filled with a viscous fluid containing ball bearings of various sizes, a stopwatch, meter stick, magnets to release the ball bearings, a video camera and computer analysis equipment.

WARM UP

1. **Draw a picture of a bead, immersed in fluid, dropping with some velocity along the vertical direction. In this picture, draw and label all the forces acting on the bead.**
2. **Write down the expression for the buoyant force acting on the bead. What is the direction of this force?**
3. **Write down the expression for the drag force on the bead as it moves through the fluid. What is the direction of the drag force relative to the velocity? How does this force depend on the properties of the bead and the liquid?**
4. **Write down Newton's second law for the bead, putting in all the forces you identified in the previous steps. What is the value of the bead's acceleration after it has reached terminal velocity?**
5. **Solve your equation for the velocity of the bead as a function of time and find the terminal velocity. How does the terminal velocity depend on the properties of the bead and the fluid?**

PREDICTION

Restate the problem in terms of quantities you know or can measure. Beginning with basic physics principles, show how you get an equation that gives the solution to the problem. Make sure that you state any approximations or assumptions that you make.

EXPLORATION

Use a stopwatch to estimate the terminal velocity. Check if dropping the bead near the walls of the container affects the measurement. Practice dropping the ball using the magnet as a release mechanism. Decide on the best position of the camera. Decide on the range of mass and size of the beads to use for your measurements from those available. How many different beads will you need for your measurement?

Write down your measurement plan.

MEASUREMENT

Record the relevant properties of each bead. The steel balls have a density of 7780 kg/m^3 and their diameters are listed on the tubes. The density of the fluid (glycerin) is 1261 kg/m^3 and its viscosity is 1.41 kg/(m·s) .

Drop a bead and video its descent. While analyzing the video, make sure you set the scale for the axes of your graph so that you can see the data points as you take them. Determine the velocity from both the plot of position versus time and the plot of velocity versus time. Which one is more reliable?

Repeat the procedure for beads of different sizes.

ANALYSIS

Make a graph of the terminal velocity as a function of the diameter of the bead and compare it to your prediction. Does the computed value seem reasonable? Does the drag force seem to be proportional to bead velocity? To bead velocity squared?

CONCLUSION

Do your measurements agree with your predictions? If not, explain why not?

How fast does the bead reach terminal velocity? Can you tell how this time depends on the properties of the bead? How does the drag force depend on the bead velocity?

Student Assessment

- **Warm-up questions & prediction turned in every week - 1 day before lab**
  Graded for good effort
- **Computer test on chapter reading must be passed before lab**
- **Lab journal and participation grade by TA in lab**
- **4 written lab reports for a semester (1 of ~6 problems selected by TA)**
  Every person in group writes up a different problem
  A good sample lab report is posted on the class web site.
  Posted grading rubric

Lab Report Structure

- **What is the point of doing this lab?**
- **What was done?**
- **What was found?**
- **Why should anyone believe it?**
- **What does it mean?**

You are working in a research laboratory and your supervisor is required to explain your work to the budget committee. She is responsible for many such research projects. You communicate your research progress by sending her a report she can read and understand in 15 minutes or less. After reading this report she must be able to convince the committee to fund your work.

Physics satisfies the University Writing Intensive requirement because of the lab report.

Cooperative Group Problem Solving is an Implementation of Cognitive Apprenticeship

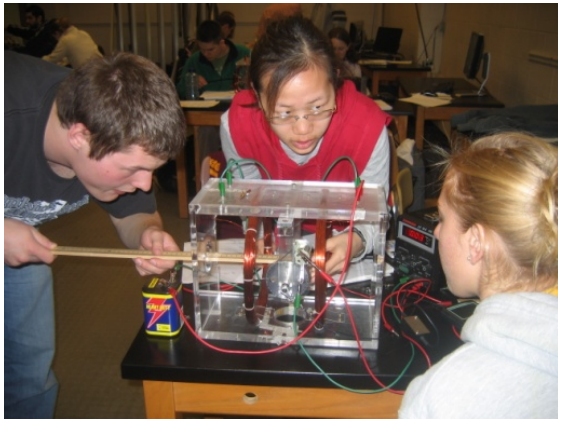
Student builds knowledge using their existing mental framework

Each student constructs their knowledge in a different way

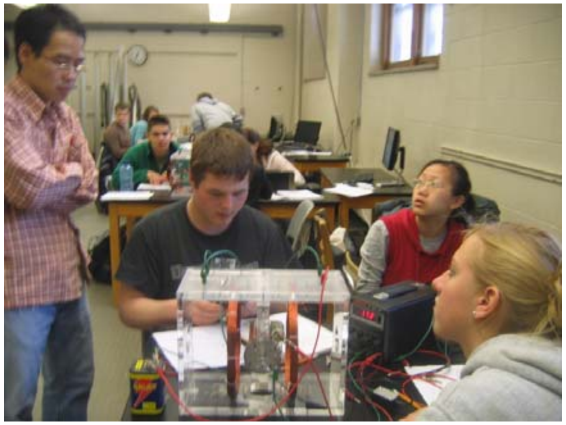
Active learning is not following a predetermined learning progression

Essential Elements

1. **Problems that require decisions connected to each student's mental framework.**
2. **Cooperative Groups to provide coaching to students while solving problems**
3. **Instructors who are aware of the teaching goals and how to achieve them.**



Peer coaching



Instructor coaching

Email after Introductory Physics for Biology & Pre-Medical Students May, 2013

I am one of your former students in PHYS 1201. I would like to thank you for your efforts in teaching us physics and guiding us through many difficult problems. I am currently studying for the MCAT and realized that your course, even though I hated it in the beginning, has helped me think critically and work through problems in an organized manner.

Have a great summer and best wishes,

first semester – Physics for Biology Majors

Week	Topic
1-3	**Forces, Torques & Equilibrium (includes fluids)**
4-5	**Force, Energy Transfer, Conservation of Energy**
6	**Potential Energy (includes fluid flow)**
7-8	**Predicting Motion – Dynamics & Oscillations**
9-10	**Predicting Non-repetitive Motion (includes motion in fluids)**

Week	Topic
11-12	**Energy & Thermal Processes**
12-14	**Cyclic Processes, Energy, Free Energy**

Includes fluid statics and dynamics, thermodynamics

No momentum, rotational kinematics, or rotational kinematics.

Reduced constant acceleration kinematics.

Content second semester – Physics for Biology Majors

Week	Topic
1-3	**Geometrical Optics- Energy Transfer by Light**
4-6	**D.C. Circuits- Energy Transfer by Electricity**
7-8	**Electric Force and Electric Field**
8-9	**Energy and Electric Potential**
10-11	**Magnetic Fields and Forces**

Week	Topic
12-13	**Changing Magnetic Fields, Electric Fields, and Potential**
13-15	**Electromagnetic Wave Optics – Interfere and Diffraction**
15	**Nuclear Spins and MRI**

OK for most physicists but some want to teach circuits after electric potential

Includes optics

No Gauss' Law, Biot-Savart Law, AC Circuits, Maxwell's Equations

Lab report grading rubric

Earns No Points	Earns Full Points	Possible
Argument		
• no clear argument • logic does not flow • gaps in content • leaves reader with questions • basis of argument is incorrect physics	• complete, cogent, flowing argument • context, execution, analysis, conclusion all present • leaves reader satisfied • correct physics used	**3**
Technical Style		
• vocabulary, syntax, etc. inappropriate for scientific writing • necessary nonverbal media absent or poorly constructed • subjective, fanciful, or appealing to emotions • jarringly inconsistent	• language is appropriate • nonverbal media present where appropriate, well constructed, well incorporated • objective, indicative, logical style • consistent style • division into sections is helpful	**3**
Use of Physics		
• predictions with no or incorrect physics justification • experiment unjustified by physics • experiment tests wrong phenomenon • theory absent from consideration of premise, predictions, and results	• predictions are justified by clear physics • experiment is based on sound physics and actually tests phenomenon in question • results interpreted with physic theory to clear, appropriate conclusion	**6**

Quantitativeness		
• statements are vague or arbitrary • analysis is inappropriately qualitative • error analysis not used to evaluate prediction or find result • numbers, equations, units, uncertainties missing or inappropriate • analysis based on incorrect physics	• consistently quantitative • equations, numbers with units, uncertainties throughout • prediction confirmed or denied, result found by error analysis • results, conclusions based on data • results, conclusions based on correct physics	6
Total		
Bonus if everyone in group scores greater than 90%		**3**

This is one of the University's Writing Intensive Courses

Students need to take 2 lower division and 2 upper division

The End

Please visit our website for more information:

http://groups.physics.umn.edu/physed/

The best is the enemy of the good.

"le mieux est l'ennemi du bien"

Voltaire