Developing student expectations in algebra-based physics

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How does having a theoretical frame (soft paradigm) affect instruction?

- Putting student learning into a two-level resources paradigm affects many aspects of instruction.
  - Choice of goals
  - Method of delivery
  - Choice of evaluation tools

Learning How to Learn Science: Physics for bioscience majors

- Funded by NSF- ROLE (Research on Learning in Education)
- Focus on algebra-based physics
- Supports
  - research into "meta-learning"
  - development of learning environments to help foster meta-learning in College Physics

Meta-learning

- Metacognition —
  analyzing their own thinking including self-knowledge and assessment and control decisions
- Epistemology —
  what students believe about knowledge and learning
- Expectations —
  what students think is appropriate for this particular physics course
- Mental models —
  coherent organizational structures providing access to associated knowledge

Personnel: Learning How to Learn Science

- Faculty
  - David Hammer
  - Joe Redish
- Visitors
  - Seth Rosenberg (AY '00-01)
  - Lubna Rana (summer '01)
- Postdocs
  - Andy Elby
  - Laura Lising
  - Rachel Scherr
- Grad Students
  - Rebecca Lippmann
  - Jon Tuminaro
  - Tim McCaskey
  - Paul Gresser
  - Ray Hodges
- Undergraduates
  - Leila Malieri
  - Nora McDermott-Taboori (Vassar summer '01)
  - Kara Gray (KSU summer '02)
  - Scott Snowman (summer '02)

Algebra-Based Physics:

- Environment (two 14 week semesters)
  - 100-200 students per class (1 prof, 2-3 GAs)
  - Lecture (150 minutes / week)
  - Recitation (50 minutes / week)
  - Lab (110 minutes / week)
  - Partially graded homework each week
- Population Characteristics
  - Predominantly female. (~60%)
  - Completed two semesters of calculus (>95%) but less confident about math than engineers.
  - Mostly biological science majors. (50-80%) (The college of life sciences requires physics.)
  - Not all pre-meds. (~30-40%)
  - Often juniors and seniors. (50-80%)

Messages and meta-messages

- Our two-level cognitive paradigm leads us to focus not only on
  - what our instruction presents about content (the "message")

  but also on
  - what our instruction is saying to the students about how it's appropriate to work with and think about the content (the "meta-message)

Some "meta-learning" changes

- Lecture
  - enhanced ILDs
  - linking to personal experience
  - focus on problem solving using core (conceptual) equations
  - use of "Elby pairs"
  - explicit discussion of how we know ("giving voice to epistemology")
- Tutorial
  - mix of UW-PEG and ABP Tutorials
  - coordinated with lab (traditional)
- Homework
  - fewer, harder, thinking problems
  - Epistemological essay questions
  - context relevant problems
  - regular block office hours
- Laboratory
  - Scientific Community (Inquiry) Labs

Meta-message 1: Link to your personal experience

- In a resources / frames / linkages picture, it is natural to suggest that a valuable resource to activate for learning physics is your personal experiences with your own physical world.
- We make a strong effort to do this
  - when we introduce new topics in lecture
  - in homework (estimation and context rich problems)
  - in examination questions.

Interactive Lectures

- When new physics is introduced, we begin by asking students to recount relevant personal experiences and core intuitions.
- Homework problems include problems with a real-world context (often chosen to show long term value for their careers).
- Exams include essay questions that ask students to reflect on their experience and intuition.

Sample Homework Problem

- One day I stopped to pick up a pizza. I put the box on the dashboard and pushed it against the windshield and left against the steering wheel to keep it from falling. I realized that it could still slide to the right or back towards the seat. Do I have to worry about it sliding more when I turn left or when I turn right? when I speed up or when I slow down? Explain your answer in terms of the physics you have learned.

Meta-message 2: Ground your knowledge in concepts

- Focus on organizational structure suggests developing strong core nodes.
- Do not proliferate equations.
- Tie critical equations to deeply-rooted concepts.
  - Kinematics are handled with only two equations.
  - These equations are related directly to the conceptual ideas.
  - Other equations are (always in lecture) obtained from processing these equations.
  - If students put in numbers early, intermediate variables appear, and not the traditional equations (e.g., $s = \frac{1}{2} at^2$)

$$\langle v \rangle = \frac{\Delta x}{\Delta t}$$

$$\langle a \rangle = \frac{\Delta v}{\Delta t}$$

Meta-message 3: Reflect on meaning and sense-making

- Homework problems are carefully chosen not only for content but for the meta-messages they send.
  - Problems that rely on everyday experience and have relevant contexts
  - Reflective essay questions highlighting epistemological issues
  - Questions linking tutorial and laboratory issues to content
  - Questions demonstrating relevance to long-term career goals (authentic biological contexts)

Typical homework problem

- A motion detector measures the time delay for a click to echo and return. The computer uses the speed of sound (~ 330 m/s at room temperature) to calculate the distance to the object.

  The speed of sound changes with temperature. At 72 °F, v_S ~ 330 m/s. At 62 °F it is about 1% smaller. Suppose we measure an object 2 m from the motion detector.

  - If T=72 °F what is the time delay Δt the computer detects before the echo returns?
  - If T= 62 °F what distance would the computer report?

Meta-message 3: Physics helps you resolve contradictions in your intuitions

- We create paired questions,
  - one which most students are likely to answer correctly,
  - one which students are likely to answer with a common misconception.
- We then help them to see there is a contradiction in their thinking and help them resolve it.
- It sends a different "meta-message"
  - not that "physics is right, your intuition wrong"
  - rather, that "physics helps you resolve contradictions in your intuitions."

"Elby pairs"

- Elby introduced a method that carried the familiar cognitive conflict approach a step farther.
- He creates paired questions,
  - one which most students are likely to answer correctly,
  - one which students are likely to answer with a common misconception.
- He then leads them to see there is a contradiction in their thinking and helps them resolve it.
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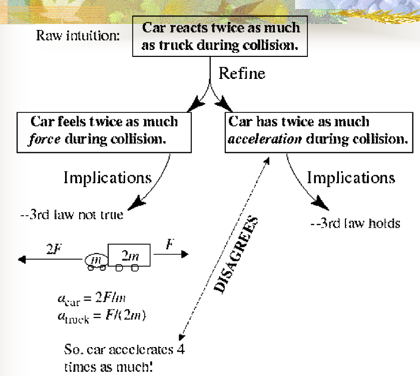
An Example: Group Discussion and Lab

1. A truck rams into a parked car.
   (a) Intuitively, which is larger during the collision: the force exerted by the truck on the car, or the force exerted by the car on the truck?
   (b) Suppose the truck has mass 1000 kg and the car has mass 500 kg. During the collision, suppose the truck loses 5 m/s of speed. Keeping in mind that the car is half as heavy as the truck, how much speed does the car gain during the collision? Visualize the situation, and trust your instincts.

2. (Experiment) To simulate this scenario, make the "truck" (a cart with extra weight) crash into the "car" (a regular cart). The truck and car both have force sensors attached. Do whatever experiments you want, to see when Newton's 3rd law applies.



Evaluation: Look at the population in 4 ways

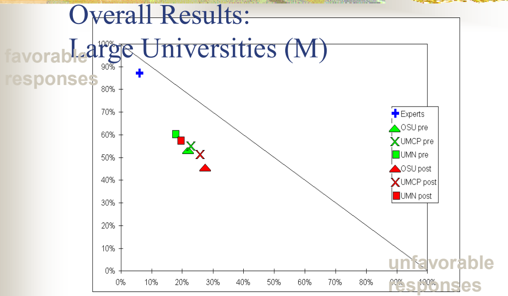
- MPEX pre-post survey
- Standardized concept tests
- Pre-post interviews, our students and from other classes
- Actual observed behavior in group-learning environments — tutorial and lab

The MPEX Survey*

- The goal is to determine the distribution and evolution of students' cognitive attitudes —beliefs that have an effect on what they learn in a physics class.
- The MPEX contains 34 statements with which students are asked to agree or disagree on a 5 point scale.
- The MPEX has been delivered at more than 20 colleges and universities to more than 5000 students.
- It probes independence, coherence, concepts awareness, reality link, and math link.

** E. F. Redish, J. M. Saul, and R. N. Steinberg, Am. J. Phys.* ***66*** *212-224(1998).*

Overall Results: Large Universities (M)



- Introductory mechanics (C) at 3 large research universities: ~500 each
- Initial distribution far from ideal.
- Result of instruction is a loss.

Overall MPEX Results

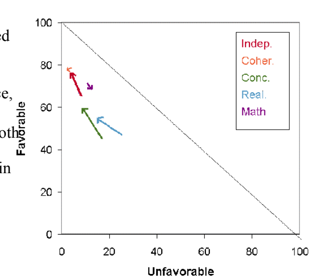
- In large lecture classes, a semester of physics instruction produces a deterioration.
- This is even true in reformed classes that are successful in producing substantial gains in students' learning of basic concepts.
- Smaller classes where the class focuses on explicit discussion of intuition building can produce substantial improvements.

Preliminary Results

- Introducing some of these elements in Fall 2000 (N = 60)
  - We obtained the largest percentage gains we have ever recorded at Maryland on a standard mechanics conceptual test.
  - We recorded the first improvement on the MPEX that we have ever obtained in a large lecture class.

MPEX Results in LtLS Trial

- Coherence and math started high and remained high.
- Strong improvements in independence, coherence, and reality.
- Improvements represent both increases in favorable and decrease in unfavorable responses.



Some notable gains (N = 60; F = disagree)

- "Problem solving" in physics basically means matching problems with facts or equations and then substituting values to get a number. (#4)

	F	N	U
Pre	66%	30%	4%
Post	91%	9%	0%

- My grade in this course is primarily determined by how familiar I am with the material. Insight or creativity has little to do with it. (#13)

Pre	57%	40%	3%
Post	79%	19%	2%

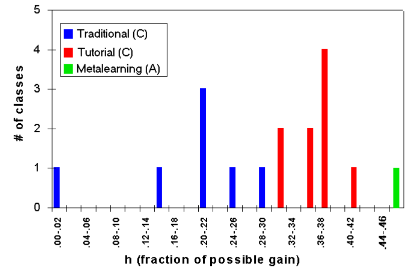
- Learning physics is a matter of acquiring knowledge that is specifically located in the laws, principles, and equations given in class and/or in the textbook. (#14)

Pre	36%	53%	11%
Post	64%	34%	2%

- The most crucial thing in solving a physics problem is finding the right equation to use. (#19)

Pre	45%	45%	10%
Post	72%	26%	2%

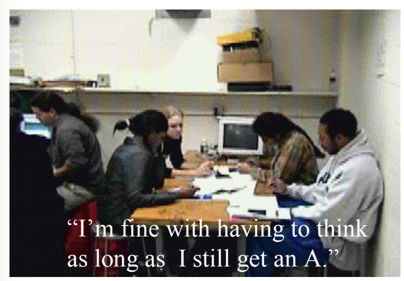
Fractional gains on conceptual test of Newtonian mechanics



What do the students say? Interviews

- Traditional algebra based intro physics
  - 10 interviews
  - After first exam in first semester
- Meta-learning class
  - 13 interviews at end of year
  - pre and post surveys
  - videotapes of lab and tutorial

Once upon a time, in a tutorial room far, far away….



Will you use any of this in two years?

According to traditional students…

No (6 / 10)

"physics has nothing to do with my major, I know I'm just going to take the class, and that's about it.… I know it's not going to help me in my later career, but biochem, at least it has some applications"
Beach

It's possible (1 / 10)

"like biomechanics, with the torque around your wrists and the pressure that you put on a bone that causes it to break.… I could see how this could be relevant if know it, but since I don't, I'm just praying that it's not going to be relevant."
Liz

They tell me I will (1 / 10)

"So I believe that people that planned the physics, they know that one day these people are going to use physics, that's why it's there. So I think it will be very helpful, because they've planned it like that."
Uta

Will you use any of this in two years?

According to our new and improved students…

Content Useful (7 / 13)

"a lot of things I learned here that are biology related obviously have immediate benefits….the homework problem we just returned this week with the radioactive nuclei of the gold, the cancer, I can see how that relates and I can understand from the physics there and the biology that I've learned…"
Thomas

Communication Skills (2 / 13)

"unlike a lot of chemistry and stuff like that, you're always working with other people, so I felt like this class really helped me to be able to communicate about science with other people… sometimes talking about science can be kind of complicated and everybody has their own ways of looking at things sometimes, and being able to express the way that I justify a situation both helps me to understand it and sometimes helps other people to understand more.
Jacob

Will you use any of this in two years?

According to our new and improved students…

Problem Solving (7 / 13)

"I now have the ability to look back at different problems and divulge more, to kind of step back from them and overall look at it and see if there's a way I can solve it using what I know, not having to ask for help.… Because I was actually able to solve problems in other classes..." Arnold

MCAT (2 / 13)

"My friends in the other classes they sit there and memorize formulas and I would just look at something and try to understand what's behind it and I find that I do better on the [MCAT] diagnostic tests than they are, and they're just like whoa, because I used to be really bad at physics..." Joshua

Conclusion

- There is more to teaching a good science class than
  - making sure the content is presented well
  - making sure the students can solve problems
  - making sure the students understand concepts
- First rate teachers have always known this.
- We are beginning to understand what's involved in getting students to learn to think physics as well as learn the facts.