Research, Innovation and Reform in Physics Education

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Some fraction of students in introductory physics have always done “well”

- High-performing students seem to master concepts and problem-solving techniques, and do well in follow-up courses.
- The proportion of high-performing students varies greatly, depending on institution and student population.
- Many – if not most – students do not fall in the high-performing category.
- Even most high-performing students could benefit from improved instruction.

Goals of Improved Instruction

- Increase knowledge of physics concepts, and problem-solving ability, for majority of enrolled students (especially in introductory courses).
- Improve attitudes of students toward physics:
  - understanding of scientific process
  - enjoyment of physics instruction

Role of Physics Education Research

- Probe “alternative conceptions” of physical reality (misconceptions, preconceptions, etc.)
- Investigate particular conceptual stumbling blocks on road to understanding physics
- Explore differences between expert and novice problem solvers

***** Apply research results to improve instruction!***

Probe “alternative conceptions” of physical reality (misconceptions, preconceptions, etc.)

“Misconceptions”/Alternative Conceptions

Student ideas about the physical world that conflict with physicists’ views

- Widely prevalent; there are some particular ideas that are almost *universally* held by beginning students
- Often very well-defined -- not merely a “lack of understanding,” but a very specific idea about what *should* be the case (but in fact is not)
- Often -- *usually* -- ***<u>very</u>*** tenacious, and hard to dislodge; ***Many*** repeated encounters with conflicting evidence required

Examples:

- An object in motion *must* be experiencing a force
- A given battery always produces the *same* current in *any* circuit
- Electric current gets “used up” as it flows around a circuit

Investigate particular conceptual stumbling blocks on road to understanding physics

Methods of Assessing Conceptual Understanding

- Conceptual surveys or "diagnostics": sets of written questions (short answer or multiple choice) emphasizing qualitative understanding *(often given "pre" and "post" instruction)*

  e.g. "Force Concept Inventory"; "Force and Motion Conceptual Evaluation"; "Conceptual Survey of Electricity"

- Students' written explanations of their reasoning

- Interviews with students

  e.g. "individual demonstration interviews" (U. Wash.): students are shown apparatus, asked to make predictions, and then asked to explain and interpret results in their own words

Learning Difficulties Explored by Research

- Difficulty in transforming among diverse *representations* (verbal, mathematical, diagrammatic, graphical, etc.) of physical concepts
- Weakness in “functional” understanding (i.e., making use of a concept to solve a problem)
- Difficulty in transforming among contexts (e.g., from “textbook” problems to “real” problems)

Difficulties in Translating Among Representations

Example: Elementary Physics Course at Southeastern Louisiana University, targeted at elementary education majors.

- Newton's second law questions, given as posttest (from "Force and Motion Conceptual Evaluation"; nearly identical questions posed in graphical, and "natural language" form):

  % correct on "force graph" questions: 56%

  % correct on "natural language" questions: 28%

This slide shows the force graphs from the FMCE

This shows the force sled problems

Changing Contexts:
Textbook Problems and "Real" Problems

- "Standard" Textbook Problem:

- [textbook problem]

- "Context-Rich" Problem (K. and P. Heller):
- [example of context-rich talk]

Testing "Functional" Understanding

Applying the concepts in unfamiliar situations: Research at the University of Washington

- Even students with good grades may perform poorly on qualitative questions in unexpected contexts

- Performance both before ***and after*** standard instruction is essentially the same

Example: This question has been presented to over 1000 students in algebra- and calculus-based lecture courses. Whether before ***or*** after instruction, fewer than 15% give correct responses.

- [five bulbs problem]

Caution: Careful probing needed!

- It is ***very easy*** to overestimate students' level of understanding.
- Students ***frequently*** give correct responses based on incorrect reasoning.
- Students' written explanations of their reasoning are powerful diagnostic tools.
- Interviews with students tend to be profoundly revealing … and extremely surprising (and disappointing!) to instructors.

[these are in Lincoln talk]

2 slides of interview transcript

[explain MBT #21]

Explore differences between expert and novice problem solvers

Results of Research: Problem Solving

Strong tendency for students to adopt various suboptimal strategies:

- start immediately with equations (searching for the unknown) instead of conducting a qualitative analysis
- work backward from desired unknown, instead of beginning with general principles and working forward from given information
- fail to identify "implicit" procedural aspects omitted from textbook presentations (e.g., ***when*** to use a particular equation, instead of some other one)
- fail to use multiple representations (diagrams, graphs, etc.) to help analyze problem

Cf. David P. Maloney, *Research on Problem Solving: Physics (1994)*

But … ***some*** students learn efficiently . . .

- Highly successful physics students (e.g., future physics instructors!) are ***"active learners."***
  - they continuously probe their own understanding of a concept (pose their own questions; examine varied contexts; etc.)
  - they are sensitive to areas of confusion, and have the confidence to confront them directly

- Great majority of students are unable to do efficient "active learning" on their own: they don't know "which questions they need to ask"
  - they require considerable prodding by instructors, aided by appropriate curricular materials
  - they need frequent confidence boosts, and hints for finding their way

Keystones of Innovative Pedagogy

- Instruction recognizes – and deliberately elicits – students' preexisting "alternative conceptions."

- To encourage active learning, students are led to engage in deeply thought-provoking activities requiring intense mental effort. ("Interactive Engagement.")

- The "process of science" is used as a means for ***learning*** science: "inquiry-based" learning. (Physics as exploration and discovery: students are not "told" things are true; instead, they are guided to ***"figure them out for themselves."***)

“Interactive Engagement”

“Interactive Engagement” methods require an <u>active learning</u> classroom:

- Very high levels of interaction between students and instructor
- Collaborative group work among students during class time
- ***<u>Intensive</u>*** active participation by students in focused learning activities during class time

Inquiry-based Learning/ “Discovery” Learning

Pedagogical methods in which students are guided through investigations to “discover” concepts

- Targeted concepts are generally ***not*** told to the students in lectures before they have an opportunity to investigate (or at least ***think*** about) the idea
- Can be implemented in the instructional laboratory (“active-learning” laboratory) where students are guided to form conclusions based on evidence they acquire
- Can be implemented in “lecture” or recitation, by guiding students through chains of reasoning utilizing printed worksheets

New Approaches to Instruction on Problem Solving

- **A. Van Heuvelen**: Require students to construct multiple representations of problem (draw pictures, diagrams, graphs, etc.)
- **P. and K. Heller:** Use “context rich” problems posed in natural language containing extraneous and irrelevant information; teach problem-solving strategy
- **F. Reif et al.:** Require students to construct problem-solving strategies, and to critically analyze strategies
- **P. D’Allesandris:** Use “goal-free” problems with no explicitly stated unknown
- **W. Leonard, R. Dufresne, and J. Mestre:** Emphasize student generation of qualitative problem-solving strategies

New Instructional Methods: Active-Learning Laboratories

- **“Microcomputer-based Labs”** *(P. Laws, R. Thornton, D. Sokoloff)*: Students make predictions and carry out detailed investigations using real-time computer-aided data acquisition, graphing, and analysis. *“Workshop Physics” (P. Laws)* is ***entirely*** lab-based instruction.

- **“Socratic-Dialogue-Inducing” Labs** *(R. Hake)*: Students carry out and analyze activities in detail, aided by “Socratic Dialoguist” instructor who asks leading questions, rather than providing ready-made answers.

New Instructional Methods: Active Learning Text/Workbooks

- ***Electric and Magnetic Interactions***, R. Chabay and B. Sherwood, Wiley, 1995.

- ***Understanding Basic Mechanics***, F. Reif, Wiley, 1995.

- ***Physics: A Contemporary Perspective***, R. Knight, Addison-Wesley, 1997-8.

- ***Six Ideas That Shaped Physics***, T. Moore, McGraw-Hill, 1998.

New Instructional Methods: University of Washington Model

"Elicit, Confront, Resolve"

Most thoroughly tested and research-based physics curricular materials; based on 20 years of ongoing work

- ***"Physics by Inquiry":*** 3-volume lab-based curriculum, primarily for elementary courses, which leads students through extended intensive group investigations. Instructors provide "leading questions" only.

- ***"Tutorials for Introductory Physics":*** Extensive set of worksheets, designed for use by general physics students working in groups of 3 or 4. Instructors provide guidance and probe understanding with "leading questions." Aimed at eliciting deep conceptual understanding of frequently misunderstood topics.

New Active-Learning Curricula for High-School Physics

- "Minds-On Physics" *(U. Mass. Physics Education Group)*
- Comprehensive Conceptual Curriculum for Physics [C^3P] *(R. Olenick)*
- PRISMS *(Physics Resources and Instructional Strategies for Motivating Students)* *(R. Unruh)*

New Instructional Methods: Active Learning in Large Classes

- ***"Active Learning Problem Sheets"*** (A. Van Heuvelen): Worksheets for in-class use, emphasizing multiple representations (verbal, pictorial, graphical, etc.)
- ***"Interactive Lecture Demonstrations"*** (R. Thornton and D. Sokoloff): students make written predictions of outcomes of demonstrations.
- ***"Peer Instruction"*** (E. Mazur): Lecture segments interspersed with challenging conceptual questions; students discuss with each other and communicate responses to instructor.
- ***"Workbook for Introductory Physics"*** (D. Meltzer and K. Manivannan): combination of multiple-choice questions for instantaneous feedback, and sequences of free-response exercises for in-class use.

Active Learning in Large Classes

- Use of “Flash-card” communication system to obtain instantaneous feedback from entire class;
- Cooperative group work using carefully structured free-response worksheets -- ***“Workbook for Introductory Physics”***
- Drastic de-emphasis of lecturing

Goal: *Transform large-class learning environment into “office” learning environment (i.e., instructor + one or two students)*

This is photo from Eric’s book

This is title page of Workbook

This is page 1 of WB

This is page 19 of WB

- This is gravity page

Effectiveness of New Methods:(I)

*Results on "Force Concept Inventory" (diagnostic exam for mechanics concepts) in terms of "g": overall learning gain (posttest - pretest) as a percentage of **maximum possible gain***

- Survey of 4500 students in 48 "interactive engagement" courses showed g = 0.48 ± 0.14

--> highly significant improvement compared to non-Interactive-Engagement classes (g = 0.23 ± 0.04)

(R. Hake, *Am. J. Phys.* **66**, 64 [1998])

- Survey of 281 students in 4 courses using "MBL" labs showed g = 0.34 (range: 0.30 - 0.40)

(non-Interactive-Engagement: g = 0.18)

(E. Redish, J. Saul, and R. Steinberg, *Am. J. Phys.* **66**, 64 [1998])

[the next slide was not shown;
here for reference]

Effectiveness of New Methods: (II)

Results on "Force and Motion Conceptual Evaluation" (diagnostic exam for mechanics concepts, involving both graphs and "natural language")

Subjects: 630 students in three noncalculus general physics courses using "MBL" labs at the University of Oregon

Results (posttest; % correct):

	Non-MBL	**MBL**
Graphical Questions	16	80
Natural Language	24	80

(R. Thornton and D. Sokoloff, *Am. J. Phys.* 66, 338 [1998])

Effectiveness of New Methods: Conceptual Understanding (III)

University of Washington, Physics Education Group

RANK THE BULBS ACCORDING TO BRIGHTNESS.

ANSWER: *A=D=E > B=C* [five bulbs in one circuit problem]

Results: Problem given to students in calculus-based course 10 weeks after completion of instruction. Proportion of correct responses is shown for:

Students in lecture class: 15%

Students in "lecture + tutorial" class: 45%

(P. Shaffer and L. McDermott, *Am. J. Phys.* **60**, 1003 [1992])

At Southeastern Louisiana University, problem given on final exam in algebra-based course using ***"Workbook for Introductory Physics"***: more than 50% correct responses.

Challenges Ahead . . .

- Many (most?) students are comfortable and familiar with more passive methods of learning science. ***Active learning methods are always challenging, and frequently frustrating for students. Some (many?) react with anger.***

- Active learning methods and curricula are not "instructor proof." Training, experience, and energy are needed to use them effectively.

Summary

- Much has been learned about how students learn physics, and about specific difficulties that are commonly encountered.

- Based on this research, many innovative instructional methods have been implemented that show evidence of significant learning gains.

- The process of improving physics instruction is likely to be endless: we will never achieve “perfection,” and there will always be more to learn about the teaching process.

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Characteristics of "Deep" Understanding

- Understand and use general principles (e.g., conservation laws, symmetry, Newton's third law)
- Possess hierarchical, connected knowledge (e.g., interconnection among conservative forces, potential energy, work-energy theorem, etc.)
- Use qualitative understanding to structure and check problem solutions (e.g., estimate answer by ignoring small quantities)