AAPT Session:

How Can Physics Education Research Help Me Teach More Effectively?

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Outline of session activities

- Perspectives from physics education research (PER) on how students learn (20 min)
- Perspectives from international studies on science education (10 min)
- Results from Implementation of PER methods in U.S. high school physics classes (10 min)
- Example of PER-based curricular materials (30 min)
  - Activity-Based Tutorials (U. of Maryland)
- Discussion and wrap-up (15 min)
Physics education research is research in the teaching and learning of physics

Two general approaches:

- **Empirical approach**
  Emphasis on student learning of specific topics (e.g., mechanics, optics, relativity)

- **Theoretical approach**
  Emphasis on predictive models of student cognition

Empirical and theoretical approaches in PER

Investigation of student understanding

Development of models of student thinking

Examination of effect on student learning

Development of instructional strategies
Types of research questions that drive theoretical studies

- How do students organize, modify, and re-organize their knowledge?*
  - Models of memory
  - Cognitive resources for learning
- How do students’ attitudes and epistemological beliefs about science affect their ability to learn science?

* This and several of the following slides are based on Chap. 2 of Teaching Physics with the Physics Suite, E. F. Redish (Wiley, 2003).

Lessons learned about working memory

Try memorizing the following sequence of 12 numbers:

3 5 2 9 1 7 0 8 6 4 3 2

Here’s another sequence to memorize:

1 7 7 6 1 8 6 5 1 9 4 1 “chunking”

Lesson: Working memory is limited
Lessons learned about *long-term memory*

Four cards are placed on a table, as shown in the diagram below. Each card has a person’s name printed on one side and a number on the other.

5  John  8  Betty

A friend tells you these cards follow a particular rule: If the name on the card is a female’s name, then the number on the other side of the card must be even.

In order to turn over the *fewest possible* cards, which cards would you turn over in order to check that your friend’s rule applies to these cards? Explain your reasoning.

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Lessons learned about *long-term memory* (continued)

Four cards are placed on a restaurant table. Each card has a person’s age printed on one side and that same person’s beverage order on the other.

12  Pepsi  31  Bud Light

You are waiting on this table and need to make sure that if a person orders an *alcoholic* beverage then that person must be *at least 21* years old.

In order to turn over the *fewest possible* cards, which cards would you turn over to make sure that you won’t serve alcohol to a minor? Explain your reasoning. (Assume that no one lied about his or her age.)
Lessons learned about long-term memory (continued)

If the order is for an alcoholic beverage, then the person’s age must be at least 21.

| 12 | Pepsi | 31 | Bud Light |

If the name is that of a female, then the number must be even.

| 5 | John | 8 | Betty |

Lesson: Long-term memory is context-dependent

Some principles from cognitive studies that help us understand student learning*

- **Constructivist principle:** Individuals build their knowledge by connecting to existing knowledge; they use this knowledge by productively creating a response to information they receive.

- **Context principle:** The knowledge individuals construct depends largely on the context.

- **Change principle:** It’s reasonably easy to learn something that matches or extends an existing mental model.
  - It’s hard to learn something we don’t almost already know.
  - It’s very difficult to change an existing mental model.

Types of research questions that drive empirical studies

- What do students understand (and do not understand) before and after instruction?

- What specific conceptual or reasoning difficulties do students have in learning particular topics?

- What specific instructional strategies seem to improve student understanding of particular topics, and under what conditions are they most effective?

Example question on 1-D kinematics: “Ball on a ramp” question

The diagram below represents a strobe photograph of the motion of the ball as it rolls up and then down the track.

At each of the locations shown, draw an arrow to indicate the direction of the acceleration of the ball. If you know the magnitude of the acceleration at any of the locations (for example, if the acceleration is zero), indicate that explicitly.

Explain the reasoning you used to determine your answers.
Correct response: “Ball on a ramp” question

Acceleration is defined as change in velocity divided by elapsed time:

\[ \vec{a} \equiv \frac{\Delta \vec{v}}{\Delta t} \]

Rolling uphill (slowing down):

At turnaround point:

Results: “Ball on a ramp” question

Introductory university physics

~ 10% correct
(whether before or after instruction)

Common incorrect response: Acceleration is zero at turnaround point.

“Acceleration = zero at the point where the ball stops rolling uphill and just before it begins rolling downhill.”

“At the top of the hill, the ball briefly is motionless and the acceleration is zero.”
A common theme from PER in introductory physics

Many students have difficulty discriminating between a quantity and its rate of change:

- position vs. velocity *
- velocity vs. acceleration (or change in velocity) *
- height vs. slope of a graph **
- electric field vs. electric potential †
- electric charge vs. electric current
- …and many other examples

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Critical limitations of traditional instruction*

- Teaching by telling is an ineffective mode of instruction for most students.
  
  Students must be intellectually active to develop a functional understanding of the content (i.e., the ability to do the reasoning needed to apply concepts and principles in situations not previously memorized).

- Facility in solving standard quantitative problems is not an adequate criterion for functional understanding.

- Study of advanced topics may not result in a deeper functional understanding of introductory topics.

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The Monotillation of Traxoline

It is very important that you learn about traxoline. Traxoline is a new form of zionter. It is montilled in Ceristanna. The Ceristannians gristerlate large amounts of fevon and then brachter it to quasel traxoline. Traxoline may well be one of our most lukized snezlaus in the future because of our zionter lescalidge.

Directions: Answer the following questions.
1. What is traxoline?
2. Where is traxoline montilled?
3. How is traxoline quasselled?
4. Why is it important to know about traxoline?

* attributed to Judy Lanier

Some principles and strategies for effective instruction in physics*

- Concepts, reasoning ability, and representational skills should be developed together in a coherent body of subject matter.

- The ability to make connections between the formalism of physics and real-world phenomena must be expressly developed.

- Common conceptual and reasoning difficulties that students encounter must be explicitly addressed.
  - Questions that require explanations of reasoning are essential for probing student thinking and assessing student progress.

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How do these principles impact student learning?

An International Perspective
8th Grade Mathematics in 3 Countries*

How would you expect these countries to rank in student math ability?

<table>
<thead>
<tr>
<th>Germany - Middle</th>
<th>Japan - Highest</th>
<th>U. S. - Lowest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Review previous material and check homework</td>
<td>Review the previous lesson</td>
<td>Review previous material and check homework</td>
</tr>
<tr>
<td>Present the topic and problems of the day</td>
<td>Present the problem for the day</td>
<td>Teacher demonstrates how to solve problems of the day</td>
</tr>
<tr>
<td>Teacher develops the procedures to solve the problem</td>
<td>Students work individually or in groups to solve problem</td>
<td>Practice with similar problems</td>
</tr>
<tr>
<td>Practice with similar problems</td>
<td>Discuss solution methods</td>
<td>Correct seatwork</td>
</tr>
<tr>
<td>Assign homework</td>
<td>Highlight and summarize major points</td>
<td>Assign homework</td>
</tr>
</tbody>
</table>

Country 3 | Country 2 | Country 1
---|---|---
United States | United States | United States


TIMSS 8th Grade Math

### TIMSS 8th Grade Science


<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Singapore</td>
<td>580</td>
<td>Singapore</td>
<td>578</td>
</tr>
<tr>
<td>Japan</td>
<td>554</td>
<td>Republic of Korea</td>
<td>558</td>
</tr>
<tr>
<td>Sweden</td>
<td>553</td>
<td>Hong Kong SAR</td>
<td>556</td>
</tr>
<tr>
<td>Korea, Republic of</td>
<td>545</td>
<td>Japan</td>
<td>552</td>
</tr>
<tr>
<td>(Bulgaria)</td>
<td>545</td>
<td>Hungary</td>
<td>543</td>
</tr>
<tr>
<td>(Netherlands)</td>
<td>541</td>
<td>Netherlands²</td>
<td>536</td>
</tr>
<tr>
<td>Hungary</td>
<td>532</td>
<td>(United States)</td>
<td>527</td>
</tr>
<tr>
<td>Belgium-Flemish</td>
<td>533</td>
<td>Australia</td>
<td>527</td>
</tr>
<tr>
<td>Slovak Republic</td>
<td>532</td>
<td>Sweden</td>
<td>524</td>
</tr>
<tr>
<td>Russian Federation</td>
<td>523</td>
<td>Slovenia</td>
<td>520</td>
</tr>
<tr>
<td>Norway</td>
<td>514</td>
<td>New Zealand</td>
<td>520</td>
</tr>
<tr>
<td>(Australia)</td>
<td>514</td>
<td>Lithuania¹</td>
<td>519</td>
</tr>
<tr>
<td>(Slovenia)</td>
<td>514</td>
<td>Slovak Republic</td>
<td>517</td>
</tr>
<tr>
<td><strong>United States</strong></td>
<td>513</td>
<td>Belgium-Flemish</td>
<td>516</td>
</tr>
<tr>
<td>New Zealand</td>
<td>511</td>
<td>Russian Federation</td>
<td>514</td>
</tr>
<tr>
<td>Hong Kong SAR</td>
<td>510</td>
<td>Latvia-LSS⁴</td>
<td>513</td>
</tr>
<tr>
<td>(Scotland)</td>
<td>501</td>
<td>Scotland²</td>
<td>512</td>
</tr>
<tr>
<td>(Latvia-LSS)⁴</td>
<td>476</td>
<td>Norway</td>
<td>494</td>
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<tr>
<td>(Romania)</td>
<td>471</td>
<td>Bulgaria</td>
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<tr>
<td>Lithuania¹</td>
<td>464</td>
<td>Romania</td>
<td>470</td>
</tr>
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<td>Iran, Islamic Republic of</td>
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<td>Iran, Islamic Republic of</td>
<td>453</td>
</tr>
<tr>
<td>Cyprus</td>
<td>452</td>
<td>Cyprus</td>
<td>441</td>
</tr>
</tbody>
</table>

### Math Scores

15-year-olds, 2003 PISA

![Math Scores Diagram](image)
### Heart of the Lesson*

<table>
<thead>
<tr>
<th>Country 1</th>
<th>Country 2</th>
<th>Country 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>Japan</td>
<td>United States</td>
</tr>
<tr>
<td>Teacher leads students through the development of advanced techniques for solving challenging problems, with students responding to frequent questions.</td>
<td>Students work on challenging problems and then share their results.</td>
<td>Teacher engages in quick-paced questions/answer with students, demonstrates methods, and asks students to work many similar problems.</td>
</tr>
</tbody>
</table>

*Stigler & Hiebert, The Teaching Gap, 1999.*
US Reform Efforts Have Not Caught on in the U.S.

“When we looked at the videos, we found little evidence of reform [in teaching methods of U.S. teachers]. . . One might even argue that Japanese lessons exemplify current U.S. reform ideas better than do U.S. lessons.”


Instructional norms are due to cultural beliefs about teaching and learning

U.S.: belief that learning occurs by mastering material incrementally, piece by piece. Practice of each small piece should be relatively error-free with high levels of success.

Japan: belief that students learn best by first struggling to solve problems, then participating in discussions about how to solve them. Frustration and confusion are a natural part of the process. Constructing connections between methods and problems requires time to explore and invent, to make mistakes, and to reflect.

One Example:
Treatment of mathematical concepts
In U.S., concepts were developed much less frequently than in Germany and Japan.

<table>
<thead>
<tr>
<th></th>
<th>Germany</th>
<th>Japan</th>
<th>U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focus on meanings behind formulas and procedures</td>
<td>80%</td>
<td>70%</td>
<td>50%</td>
</tr>
<tr>
<td>Focus on applying formulas and procedures</td>
<td>20%</td>
<td>30%</td>
<td>50%</td>
</tr>
</tbody>
</table>

- Stated
- Developed


Some principles and strategies for effective instruction in physics

- Concepts, reasoning ability, and representational skills should be developed together in a coherent body of subject matter.
- The ability to make connections between the formalism of physics and real-world phenomena must be expressly developed.
- Common conceptual and reasoning difficulties that students encounter must be explicitly addressed.
- Question that require explanations of reasoning are essential for probing student thinking and assessing student progress.

The Japanese system accomplishes these with an interactive instructional style. This style is unfamiliar to most U.S. students and U.S. teachers. PER has attempted to make interactive instructional styles more explicit and documenting their impact on student learning.

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Interactive Instruction can be Effective in the U.S.

An Example: Modeling
Modeling Instruction

- Began in Phoenix area in late 80’s through a collaboration between Arizona State and a local high school physics teacher.
- An NSF grant in the 90’s led to 8 multi-summer intensive workshops nationwide.

*Slides from K. Harper, the Ohio State University, used with permission

Modeling Instruction

- Was designated as an exemplary program by the U. S. Dept of Ed in 2001.
- Has spread teacher to teacher (N ~ 2000)
- Has solid data that students learn physics well when these methods are used

*Slides from K. Harper, the Ohio State University, used with permission
Phase 1: Model Development

- A demo and/or discussion to establish a common contextual understanding of terminology and goals
- Students design and perform their own experiments
- Students prepare whiteboards for presentation of results and conclusions.
- Students must articulate and evaluate a model for making sense of the experimental results, and respond to questions and critique from students and teacher.

*Slides from K. Harper, the Ohio State University, used with permission

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Phase 2: Model Deployment

- Students analyze a variety of problems and situations using the model.
- Again they must prepare to present and defend their arguments and conclusions.

*Slides from K. Harper, the Ohio State University, used with permission*

The Teacher’s Role – Unobtrusive Guide

- **Improves quality of student discourse**
  - insists on accurate use of scientific terms
  - promotes clarity of expressed ideas and arguments
- **Guides students in how to conduct scientific inquiry systematically**
  - Less teacher prompting needed as students gain experience
  - Supplies students with more powerful modeling tools.
- **Minimal lecturing**
  - for scaffolding new concepts & principles as needed

*Slides from K. Harper, the Ohio State University, used with permission*
How do we know it works?

The Force Concept Inventory: A 30 question multiple-choice test commonly used to assess student understanding of Newton’s Laws.

2. Imagine a head-on collision between a large truck and a small compact car. During the collision,

(A) the truck exerts a greater amount of force on the car than the car exerts on the truck
(B) the car exerts a greater amount of force on the truck than the truck exerts on the car
(C) neither exerts a force on the other, the car gets smashed simply because it gets in the way of the truck.
(D) the truck exerts a force on the car but the car doesn’t exert a force on the truck.
(E) the truck exerts the same amount of force on the car as the car exerts on the truck.

<table>
<thead>
<tr>
<th>Answer choice</th>
<th>Traditional Instruction</th>
<th>Modeling Instruction*</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-correct</td>
<td>22% ⇒ 37%</td>
<td>14% ⇒ 94%</td>
</tr>
<tr>
<td>A</td>
<td>72% ⇒ 60%</td>
<td>84% ⇒ 6%</td>
</tr>
</tbody>
</table>

*Swackhamer course, all data from Hestenes et. al., Force Concept Inventory (1992)
22. A golf ball driven down a fairway is observed to travel through the air with a trajectory (flight path) similar to that in the depiction below.

Which following force(s) is(are) acting on the golf ball during its entire flight?

1. the force of gravity
2. the force of the "hit"
3. the force of air resistance

(A) 1 only
(B) 1 and 2
(C) 1, 2, and 3
(D) 1 and 3
(E) 2 and 3

<table>
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>D-correct</td>
<td>10% ⇒ 29%</td>
<td>5% ⇒ 46%</td>
</tr>
<tr>
<td>C</td>
<td>79% ⇒ 62%</td>
<td>88% ⇒ 25%</td>
</tr>
</tbody>
</table>

*Swackhamer course, all data from Hestenes et. al., Force Concept Inventory (1992)

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Overall FCI Scores for Modeling Physics Instruction

![Bar chart showing percent correct scores for different groups.]

- Traditional Instruction: 42%
- Novice Modelers: 53%
- Expert Modelers: 69%

Average Pretest Score: 26%
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Discussion Questions

1. What aspects of your teaching are consistent with the ideas from PER presented today? What aspects might be inconsistent?
2. What changes would you like to make in your instruction to incorporate some of the ideas presented today?
3. What do you think some of the benefits of making such changes might be?
4. What are some of the barriers to making such changes?

Thank You

General Questions/Comments