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:

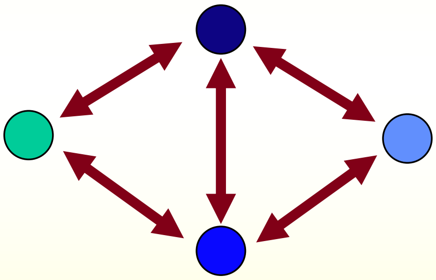
- Empirical approach

  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?

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* 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:

$$\underbrace{1\ \ 7\ \ 7\ \ 6}\ \ \underbrace{1\ \ 8\ \ 6\ \ 5}\ \ \underbrace{1\ \ 9\ \ 4\ \ 1}$$

"chunking"

Lesson: *Working memory is* ***<u>limited</u>***

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.

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* ***<u>context-dependent</u>***

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.

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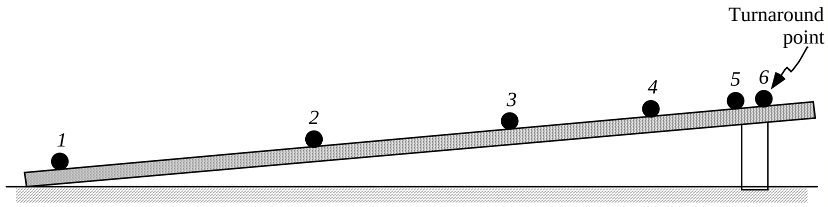
* E. F. Redish, *Teaching Physics with the Physics Suite,* (Wiley, 2003).

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.



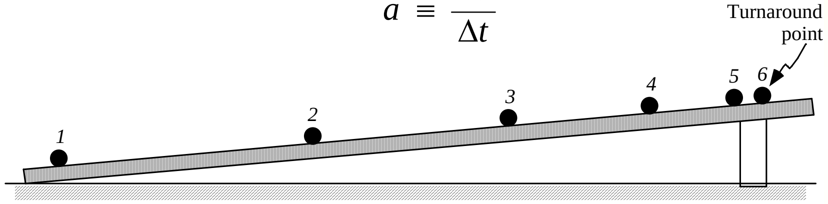
At each of the locations shown, draw an arrow to indicate the direction of the *acceleration* of the ball. If you know the magnitude of the acceleration at any of the locations (for example, if the acceleration is zero), indicate that explicitly.

Explain the reasoning you used to determine your answers.

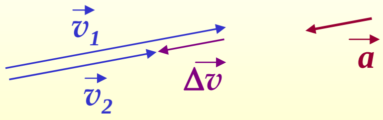
Correct response: “Ball on a ramp” question

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

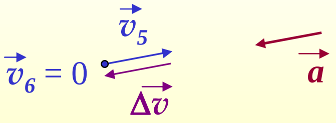
$$\vec{a} \equiv \frac{\Delta\vec{v}}{\Delta t}$$



Rolling uphill (slowing down):



At turnaround point:

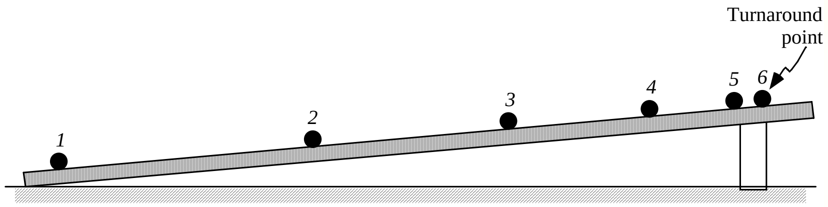


Results: “Ball on a ramp” question

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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* Trowbridge and McDermott, Am. J. Phys. **48** (1980) and **49** (1981); Shaffer and McDermott, Am. J. Phys. **73** (2005).

** McDermott, Rosenquist, and van Zee, Am. J. Phys. **55** (1987).

† Allain, Ph.D. dissertation, NCSU, 2001; Maloney *et al.*, Am. J. Phys. Suppl. **69** (2001).

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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*L.C. McDermott, Am. J. Phys. **61**, 295 – 298 (1993).

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 lescelidge.

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?

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* 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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*L.C. McDermott, Am. J. Phys. **59**, 301 – 315 (1991).

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How do these principles impact student learning?

An International Perspective

8th Grade Mathematics in 3 Countries*

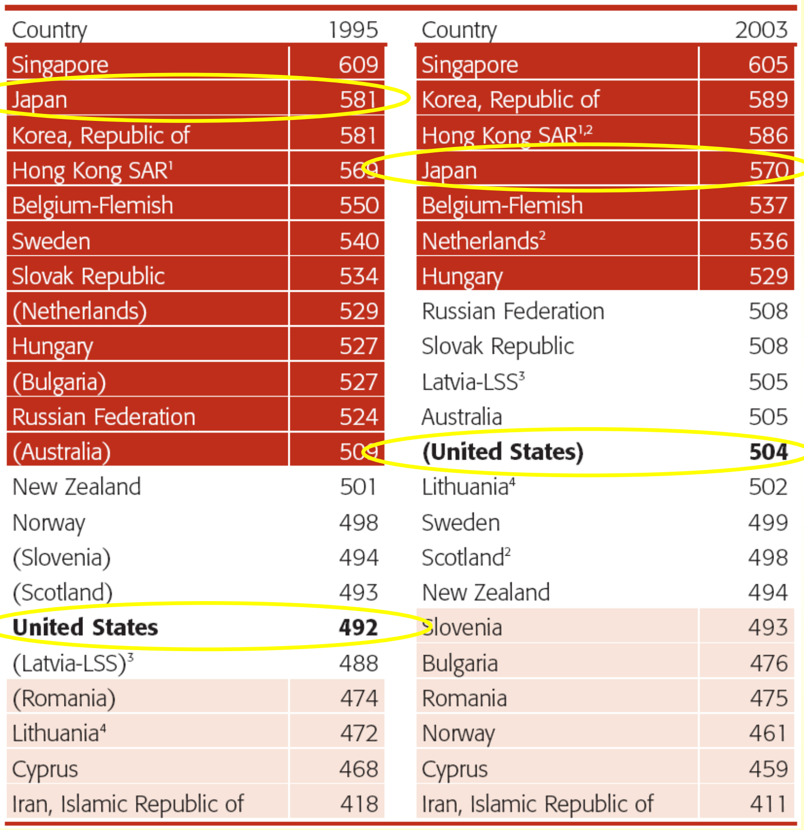
How would you expect these countries to rank in student math ability?

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

*Stigler & Hiebert, The Teaching Gap, 1999.

TIMSS

8th Grade Math

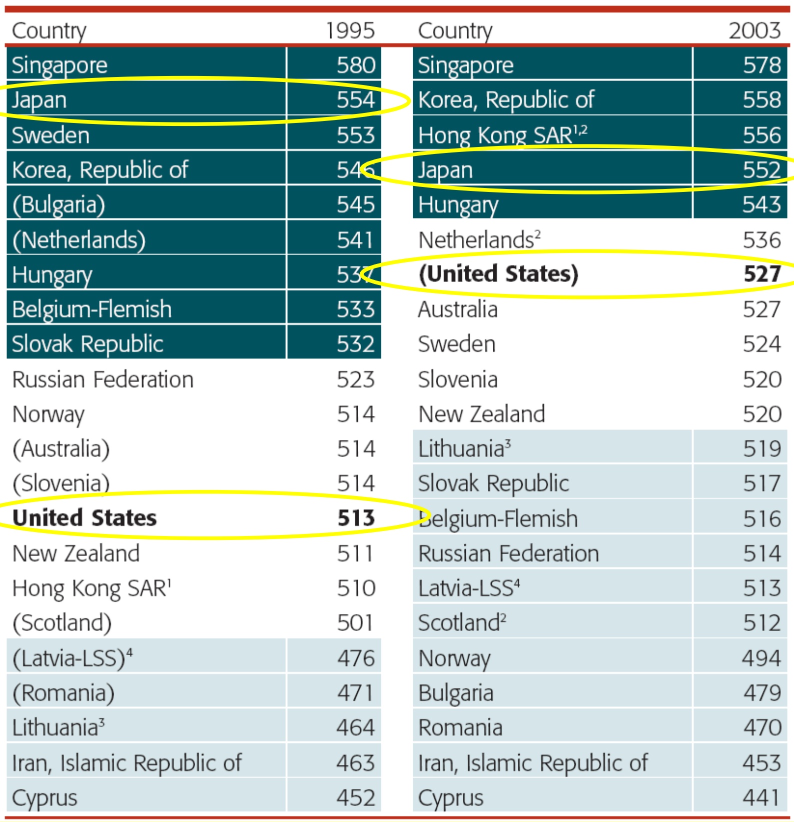


Country	1995	Country	2003
Singapore	609	Singapore	605
Japan	581	Korea, Republic of	589
Korea, Republic of	581	Hong Kong SAR[1,2]	586
Hong Kong SAR[1]	569	Japan	570
Belgium-Flemish	550	Belgium-Flemish	537
Sweden	540	Netherlands[2]	536
Slovak Republic	534	Hungary	529
(Netherlands)	529	Russian Federation	508
Hungary	527	Slovak Republic	508
(Bulgaria)	527	Latvia-LSS[3]	505
Russian Federation	524	Australia	505
(Australia)	509	**(United States)**	**504**
New Zealand	501	Lithuania[4]	502
Norway	498	Sweden	499
(Slovenia)	494	Scotland[2]	498
(Scotland)	493	New Zealand	494
United States	**492**	Slovenia	493
(Latvia-LSS)[3]	488	Bulgaria	476
(Romania)	474	Romania	475
Lithuania[4]	472	Norway	461
Cyprus	468	Cyprus	459
Iran, Islamic Republic of	418	Iran, Islamic Republic of	411

From
http://nces.ed.gov/pubs2005/2005005.pdf

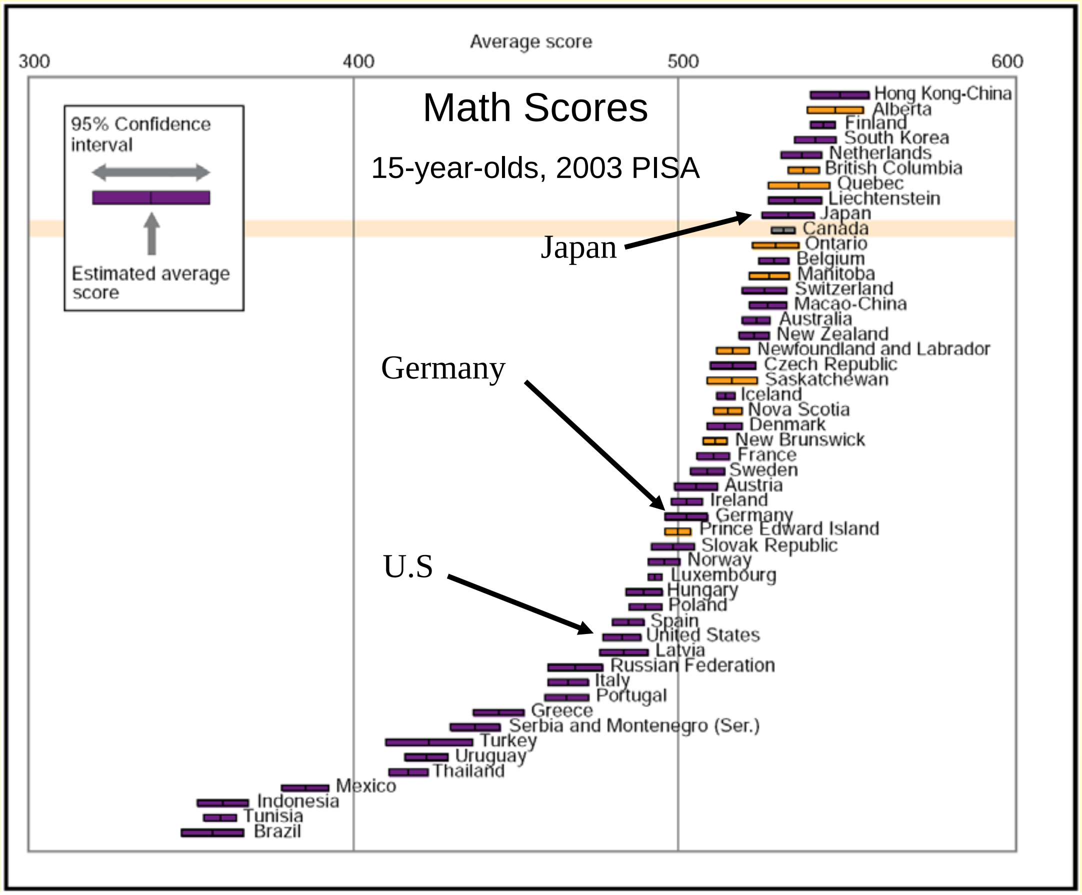
TIMSS

8th Grade Science



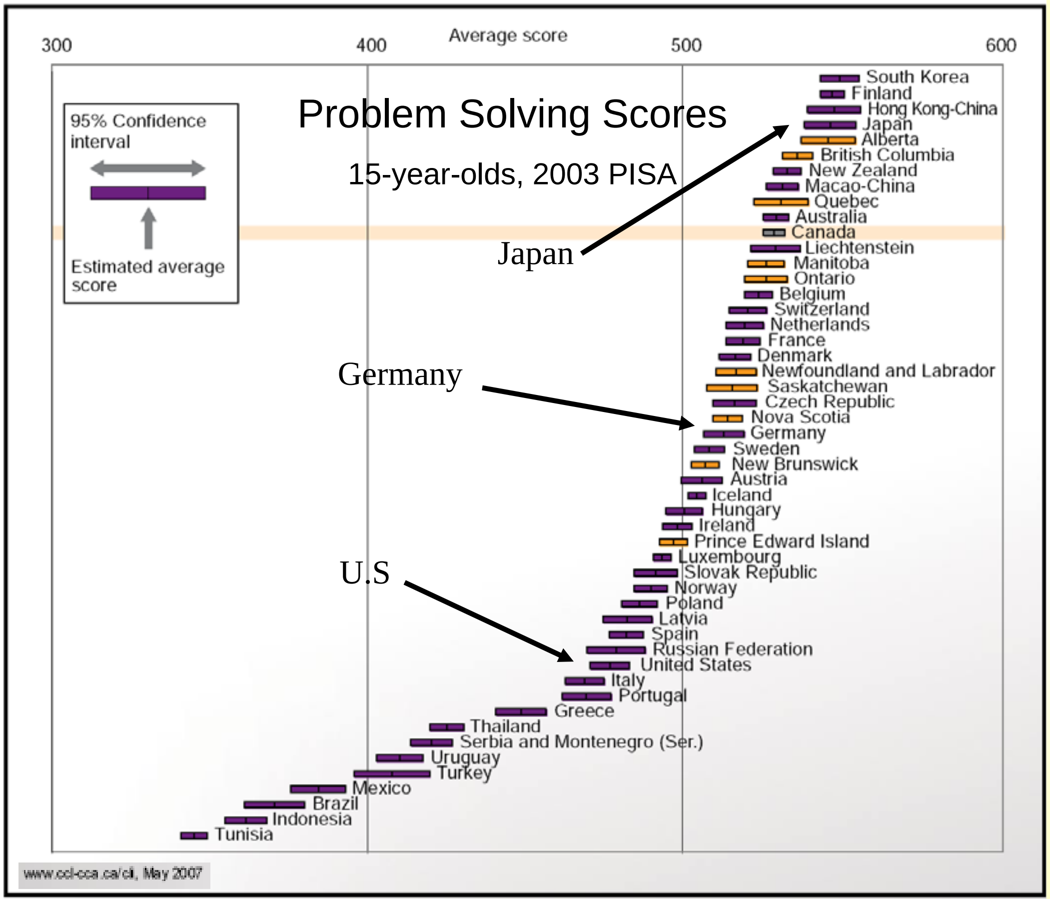
Country	1995	Country	2003
Singapore	580	Singapore	578
Japan	554	Korea, Republic of	558
Sweden	553	Hong Kong SAR[1,2]	556
Korea, Republic of	546	Japan	552
(Bulgaria)	545	Hungary	543
(Netherlands)	541	Netherlands[2]	536
Hungary	537	**(United States)**	**527**
Belgium-Flemish	533	Australia	527
Slovak Republic	532	Sweden	524
Russian Federation	523	Slovenia	520
Norway	514	New Zealand	520
(Australia)	514	Lithuania[3]	519
(Slovenia)	514	Slovak Republic	517
United States	**513**	Belgium-Flemish	516
New Zealand	511	Russian Federation	514
Hong Kong SAR[1]	510	Latvia-LSS[4]	513
(Scotland)	501	Scotland[2]	512
(Latvia-LSS)[4]	476	Norway	494
(Romania)	471	Bulgaria	479
Lithuania[3]	464	Romania	470
Iran, Islamic Republic of	463	Iran, Islamic Republic of	453
Cyprus	452	Cyprus	441

From
http://nces.ed.gov/pubs2005/2005005.pdf



Math Scores

15-year-olds, 2003 PISA



Problem Solving Scores

15-year-olds, 2003 PISA

Japan

Germany

U.S

Heart of the Lesson*

Country 1	Country 2	Country 3
Germany	Japan	United States
Teacher leads students through the development of advanced techniques for solving challenging problems, with students responding to frequent questions.	Students work on challenging problems and then share their results.	Teacher engages in quick-paced questions/answer with students, demonstrates methods, and asks students to work many similar problems.
Middle student performance	**Highest student performance**	**Lowest student performance**

*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."

*Stigler & Hiebert, The Teaching Gap, 1999, p. 106.

Instructional norms are due to cultural beliefs about teaching and learning

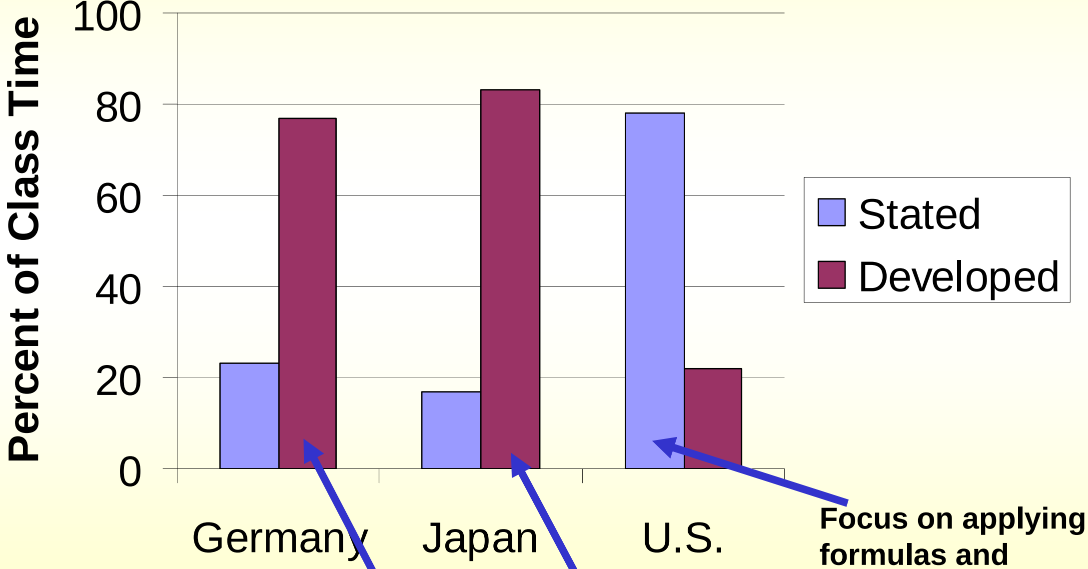
U.S.: belief that learning occurs by mastering material incrementally, piece by piece. Practice of each small piece should be relatively error-free with high levels of success.

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.

*Stigler & Hiebert, The Teaching Gap, 1999.

One Example:
Treatment of mathematical concepts

In U.S., concepts were developed much less frequently than in Germany and Japan.



Focus on meanings behind formulas and procedures

Focus on applying formulas and procedures

*Stigler & Hiebert, The Teaching Gap, 1999, p. 61.

Some principles and strategies for effective instruction in ph

- Concepts, reasoning ab
  developed to

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.

e essential for
udent progress.

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*L. Dermott, Am. J. Phys. **59**, 301 – 315 (1991).

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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

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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 1:
Model Development

<u>Japan:</u> 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.

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

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

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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?

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

Force Concept Inventory

By David Hestenes, Malcolm Wells, and Gregg Swackhamer

Every student begins physics with a well-established system of commonsense beliefs about how the physical world works derived from years of personal experience. Over the last decade, physics education research has established that these beliefs play a dominant role in introductory physics. Instruction that does not take them into account is almost totally ineffective, at least for the majority of students.

Specifically, it has been established that[1] (1) commonsense beliefs about motion and force are incompatible with Newtonian concepts in most respects, (2) conventional physics instruction produces little change in these beliefs, and (3) this result is independent of the instructor and the mode of instruction. The implications could not be more serious. Since the students have evidently not learned the most basic Newtonian concepts, they must have failed to comprehend most of the material in the course. They have been forced to cope with the subject by rote memorization of isolated fragments and by carrying out meaningless tasks. No wonder so many are repelled! The few who are successful have become so by their own devices, the course and the teacher having supplied only the opportunity and perhaps inspiration.

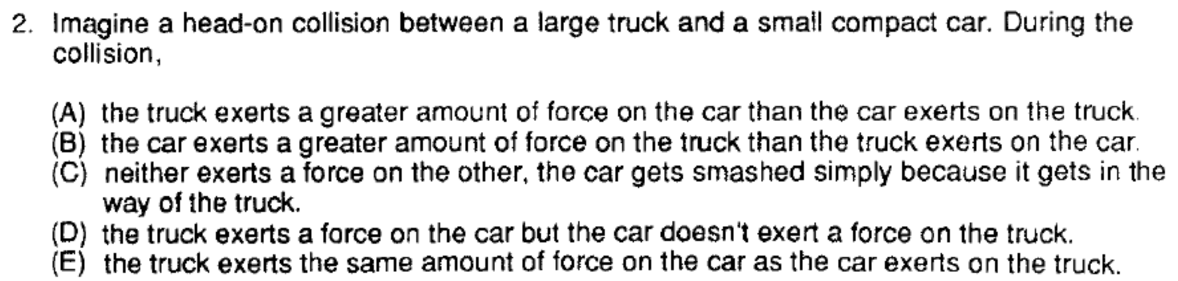
The authors, David Hestenes, Malcolm Wells, and Gregg Swackhamer are trying to make a point!

David Hestenes *is a professor of theoretical physics at Arizona State University. He has been active in physics education research for more than a decade. He also has current research in relativistic electron theory and neural network modeling of the brain (Department of Physics and Astronomy, Arizona State University, Tempe, AZ 85287).*

Malcolm Wells *has been a high-school physics teacher for three decades. In 1986 he received the Presidential Award for Excellence in Science Education. In 1987 he completed a doctorate in physics education research. He is currently collaborating with Hestenes on an NSF grant for educational research and teacher enhancement (Marcos de Niza High School, Tempe, AZ 85283).*

Gregg Swackhamer *has taught high-school physics for 13 years. He has B.S. and M.A.T. degrees from Indiana University. He is currently teaching physics at Glenbrook North High School (Northbrook, IL 60062) from which he took sabbatical leave in 1989–90 to study at Arizona State University and work on this project.*

“Force Concept Inventory” VOL. 30, MARCH 1992 *THE PHYSICS TEACHER* 141

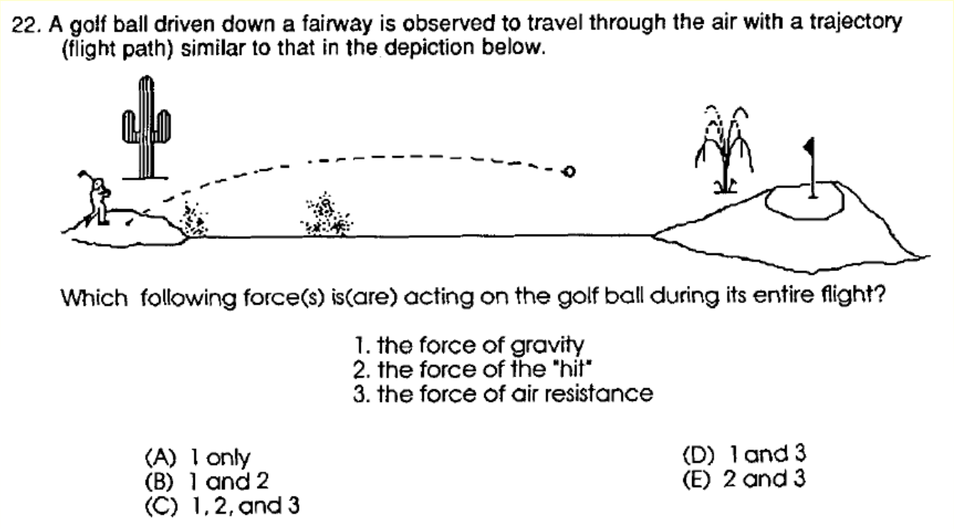


2. Imagine a head-on collision between a large truck and a small compact car. During the collision,

(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.

Answer choice	Traditional Instruction	Modeling Instruction*
E-correct	22% ⇨ 37%	14% ⇨ 94%
A	72% ⇨ 60%	84% ⇨ 6%

*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?

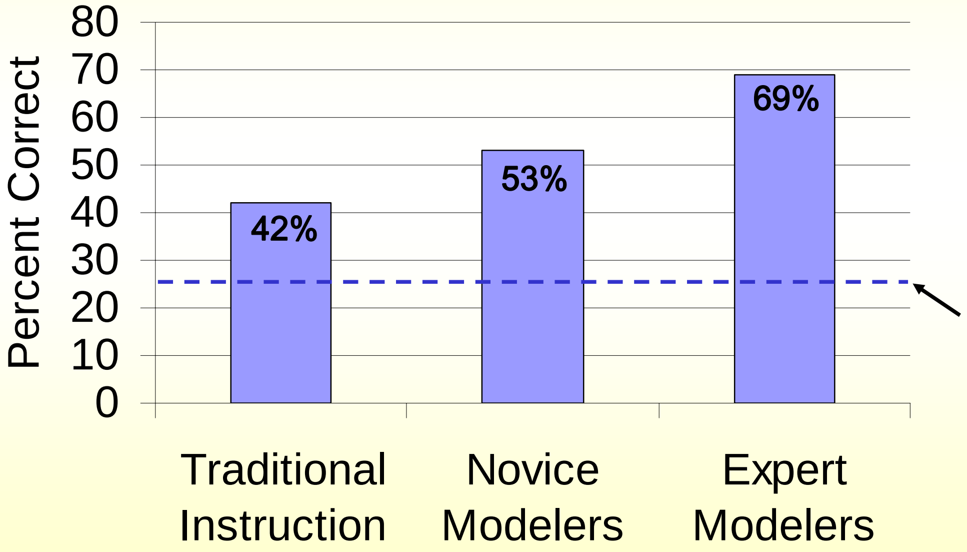
1. the force of gravity
2. the force of the "hit"
3. the force of air resistance

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

Answer choice	Traditional Instruction	Modeling Instruction*
D-correct	10% ⇨ 29%	5% ⇨ 46%
C	79% ⇨ 62%	88% ⇨ 25%

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

Overall FCI Scores for Modeling Physics Instruction



26% : Average Pretest Score

Data from http://modeling.asu.edu/

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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