Research on the Learning and Teaching of Physics:

An Important Focus for Physicists

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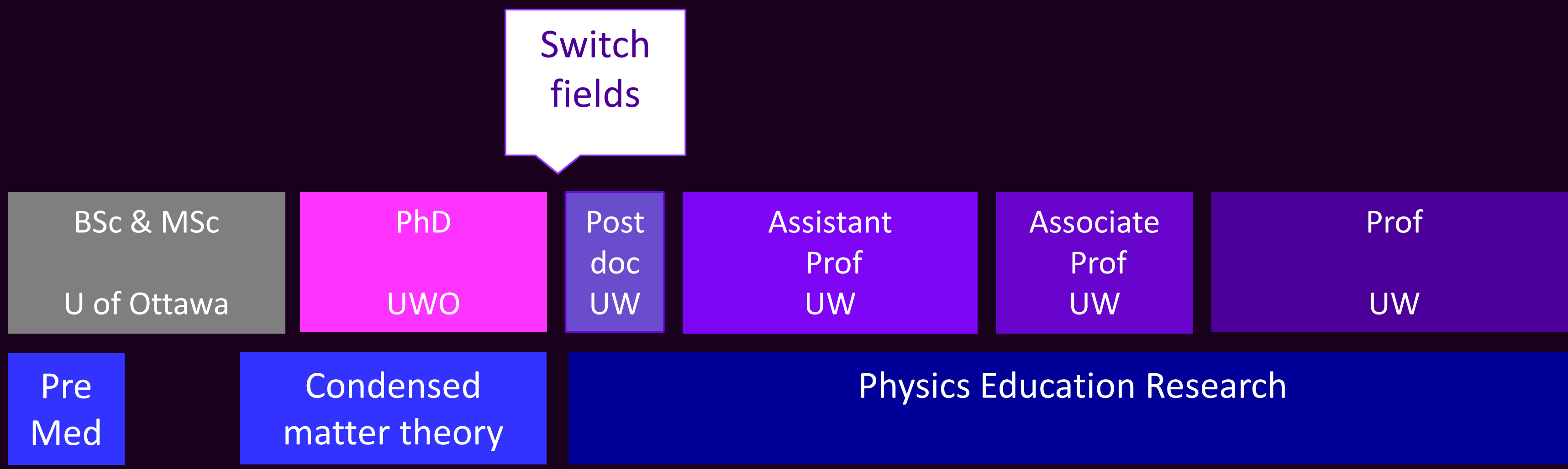
UW PHYSICS EDUCATION GROUP

My path


Switch fields
BSc & MSc
U of Ottawa
PhD
UWO
Post doc
UW
Assistant Prof
UW
Associate Prof
UW
Prof
UW
Pre Med
Condensed matter theory
Physics Education Research

Critical factors

- Early involvement in research

Physics is fundamentally creative

- Mentors

Physics is a community endeavor

Outline

- Physics Education Research (PER) in the US
- The UW Physics Education Group: An empirically oriented research program
- An illustrative example

Physics Education Research in the US

- Primary focus: teaching and learning at the university level
- Researchers are (typically) embedded in the physics community
  - many obtained a PhD in a traditional area of research
  - typically located in physics departments
  - graduate students often earn a PhD in physics

Physics Education Research in the US

Research universities with tenured/tenure-track PER physics faculty and where students can earn a PhD in Physics for PER

- University of Washington
- University of Maryland
- University of Illinois
- University of Colorado
- University of Maine
- University of Pittsburgh
- The Ohio State University
- Kansas State University
- Michigan State University
- North Dakota State Univ.
- Oregon State University
- Cornell University*

Physics Education Research in the US

- Meetings and conferences
  - American Physical Society (APS) meetings
  - American Association of Physics Teachers (AAPT) meetings
  - Physics Education Research Conference (annual)
  - Foundations and Frontiers in PER (biannual)
- Journals
  - *American Journal of Physics*
  - *Proceedings of the Physics Education Research Conference*
  - *Physical Review - Physics Education Research*
- Professional societies
  - The PER Topical Group (PERTG) of the AAPT
  - The Group on PER (GPER) of the APS

Physics Education Research (in the US)

Examples of research-based instructional strategies

- Peer instruction or “clickers” (Harvard)
- Studio or workshop-style courses (MIT, Dickinson, NC State)
- Multimedia prelectures (Illinois)
- Computer-based labs (Oregon, Tufts)
- Cooperative Group Problem Solving (Minnesota)
- Intelligent tutors (MIT)
- PhET Simulations (Colorado)
- Tutorials (UW)

See Meltzer & Thornton, Am. J. Phys. 2012

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Physics Education Group at UW

Faculty

Suzanne Brahmia*
Paula Heron
Lillian McDermott
Peter Shaffer

Lecturers and postdocs

Paul Emigh
Ryan Hazelton
Donna Messina

Physics PhD Students

Sheh Lit Chang
Lisa Goodhew
Alexis Olsho
Marshall Styczinski
Tong Wan
Bert Xu

Visitors

Jerry Feldman (GWU)
Xaoting Yue (East China Normal)
DJ Wagner (Grove City College)

Physics Education Group at UW
Former PhD students and postdocs

Brad Ambrose	*Grand Valley State U.*	Beth Lindsey	*Penn State Allegheny*
Andrew Boudreaux	*Western Washington U.*	Mike Loverude	*Cal State Fullerton*
Ximena Cid	*Cal State Dominguez Hills*	Gina Passante	*Cal State Fullerton*
Hunter Close	*Texas State San Marcos*	Amy Robertson	*Seattle Pacific U.*
Andrew Crouse	*ISG, Saudi Arabia*	Mel Sabella	*Chicago State U.*
Greg Francis	*Montana State U.*	Homeyra Sadaghiani	*Cal Poly Pomona*
Steve Kanim	*New Mexico State U.*	Rachel Scherr	*Seattle Pacific U.*
Chris Kautz	*TUHH, Germany*	David Smith	*U. of North Carolina*
Mila Kryjevskaia	*North Dakota State U.*	Richard Steinberg	*City College, New York*
		John Thompson	*U. of Maine*

And 12 others dating back to the 1970s

Physics Education Group at UW

Primary goal:

- improve student learning in physics from kindergarten through graduate school

Primary activities:

- conduct basic **research** on student understanding
- develop **instructional materials** for university-level courses
- provide **professional development** for
  - elementary, middle and high school teachers
  - university faculty and teaching assistants
  - current and future physics education researchers

Current research projects

- Investigating student learning of specific physics content in intro courses
  - E&M, Energy, Waves, Special relativity
- Investigating student learning of specific physics content in advanced courses
  - E&M, Quantum Mechanics
- Exploring the role of visualization and spatial reasoning abilities in student learning of physics
- Examining student ability to transfer from one context to another
- Assessing student reasoning ability
- Helping K-12 teachers develop scientific reasoning skills

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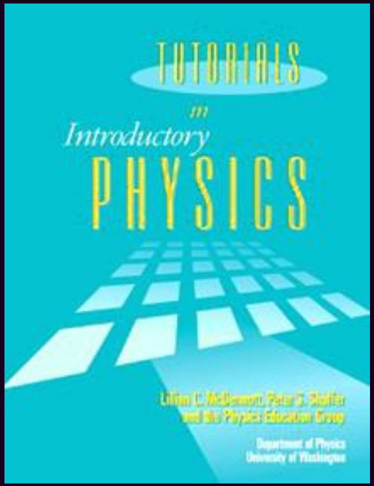
Context

- Introductory calculus-based physics at UW
  - weekly lectures, labs, and *tutorials*

- Each tutorial sequence consists of:
  - *Pretest*
  - Tutorial session
  - Homework
  - Exam question* (for 4 or 5 tutorials each quarter)



About “pretests”

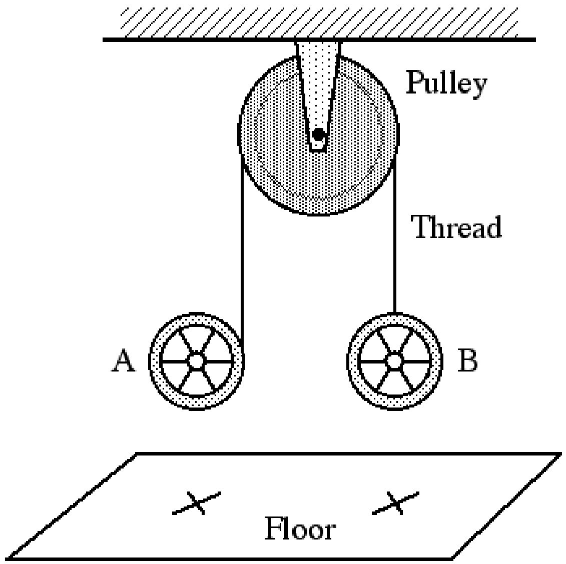
- Timing
  - precede each tutorial
  - may occur BEFORE OR AFTER lecture instruction
- Format
  - several qualitative multiple-choice questions with explanations required
- Administration
  - online (since 2000)
  - students have 15 minutes to take pretest during a 48-hr window
  - credit given for participation

For some questions we have thousands of responses from dozens of different classes taught by different professors with different textbooks, etc.

Variation in performance from class to class

Sample pretest question from mechanics

Which spool hits first?



On average, 38% of students in Intro Physics answer correctly.

PhD students do only slightly better…

Heron, *PhysRev PER 2015*

Maybe students responded incorrectly because:

- they are not very smart
- they were never taught the relevant material
- they *were* taught the material, but poorly
- they misunderstood the question or made unintended assumptions
- they weren't taking the question seriously
- they ignored their correct intuition because it was a physics test
- they don't have enough real-world experience ("kids today …")
- …

Most of these explanations, while reasonable, are not supported by evidence

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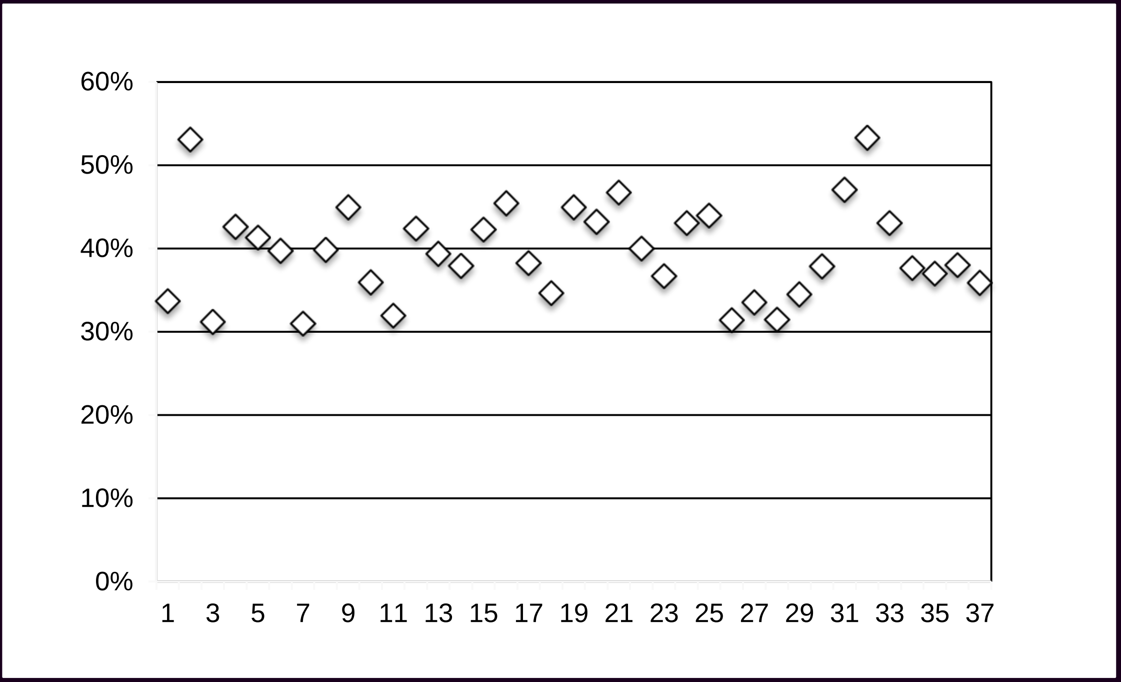
Results from 37 classes ($N_{total} > 5000$)

Different textbooks, instructors, times of day, class size, …

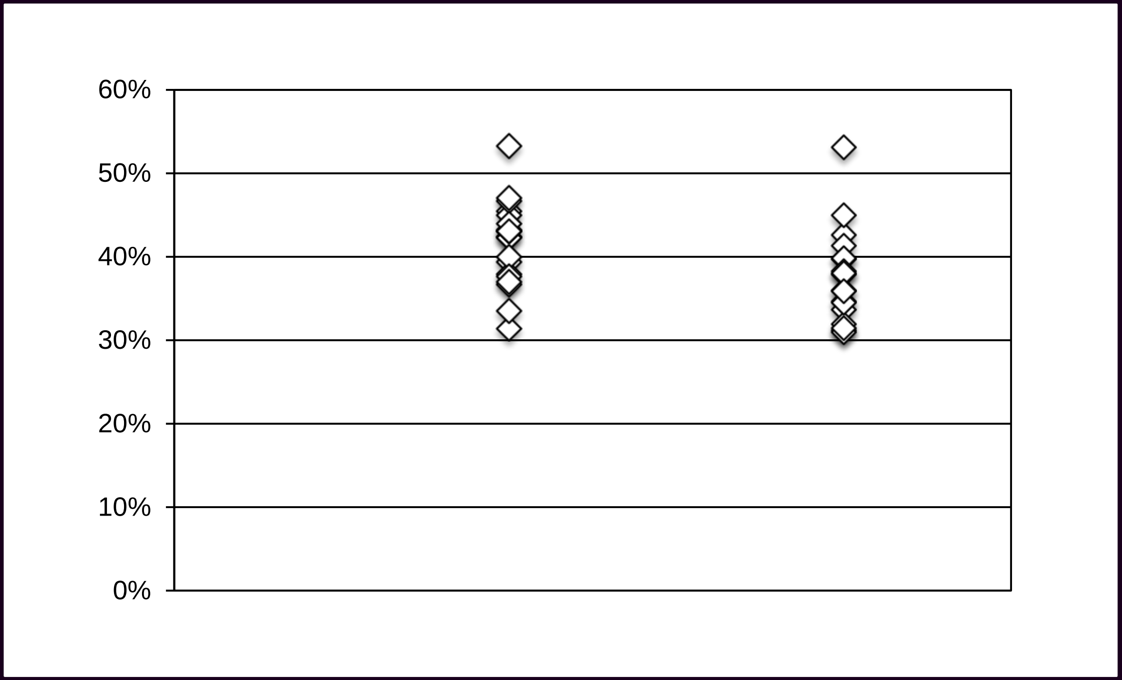
% of students in class who answered correctly



Individual classes

Effect of prior instruction on rigid-body dynamics

% of students in class who answered correctly

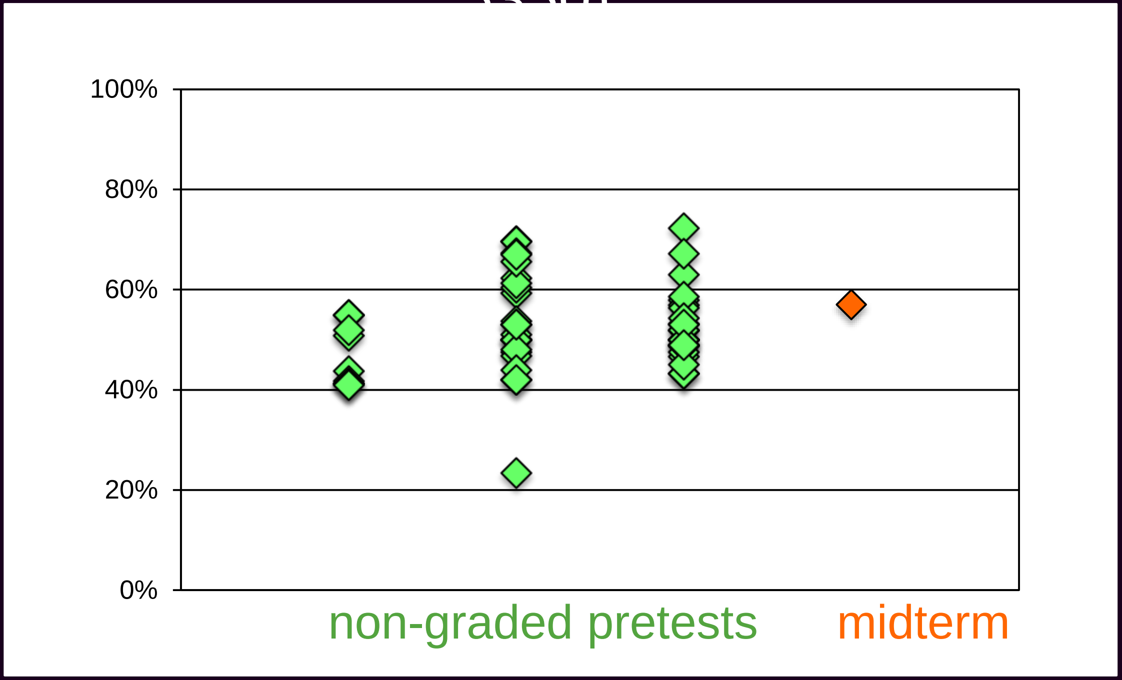


No instruction

All instruction

But … pretests aren't graded so maybe students don't take them seriously

Example: results of a question on capacitance (56 classes; N_{total} = 5350)



before during after after

None of the classes had a tutorial on the topic

- The results are similar in all classes.
- The amount of instruction on rigid body dynamics does not affect performance (typical result).

There is something innately difficult about this task, (and many others that require qualitative reasoning).

Further analysis: Multiple linear regression

- 20 randomly selected qualitative questions each given in many different classes (median number = 54) over a period of 13 years
- Multiple linear regression with several possible explanatory variables (year since 1999, time of day, class size, whether or not instruction had already occurred…)
- instruction was associated with
  - a statistically significant* positive effect on 4 questions
  - a statistically significant* negative effect on 2 questions
  - **no** effect on 14 questions
- Only one other variable had a systematic effect (year since 1999)

*$p < 0.1$

Heron, PhysRev PER, 2015

Why is learning physics challenging for so many students?

A. It is intrinsically difficult
   - Can’t (and don’t want to) do much about this

B. Everyone has pre-existing ideas that they try (consciously or unconsciously) to connect with new ideas
   - Understand these ideas and how they interact with new ideas

C. Our historical methods of teaching ignore point B
   - Develop teaching methods that take point B into account

What can we do about it?

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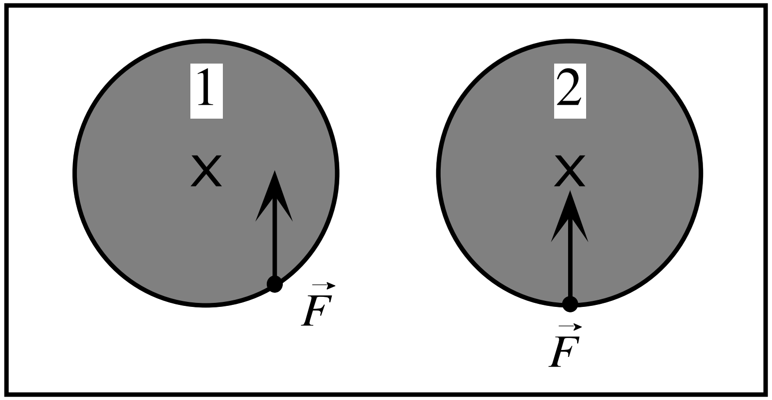
Development of a tutorial on rigid-body dynamics

Two identical pucks are on a flat, frictionless ice rink. The center of mass of each puck is marked with an 'X.' Forces of equal magnitude and direction are exerted on the pucks.

At the instant shown:
Is $|\boldsymbol{a}_{cm,1}|$ *greater than, less than, or equal to* $|\boldsymbol{a}_{cm,2}|$*?*

Top view diagram



10% to 20% of students answer correctly

Interpretation

Extensive research revealed that many students assume the effect of a force on *linear motion* depends on where the force is exerted

Specific assumptions:

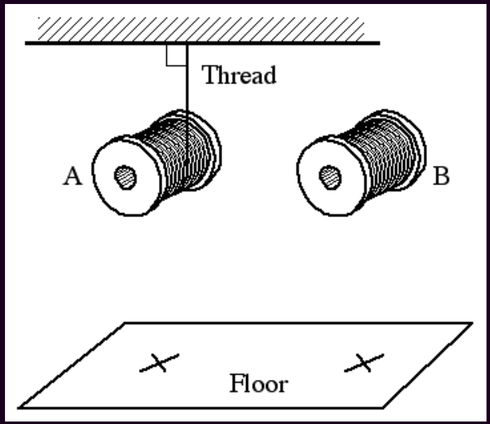
- If a force is not exerted at the center of mass*, it has a diminished effect on translational motion
- If the force is exerted at the *edge*, it contributes only to rotational motion

* i.e., the line of action passes through the center of mass

Attempts to develop a tutorial

In early versions, students:

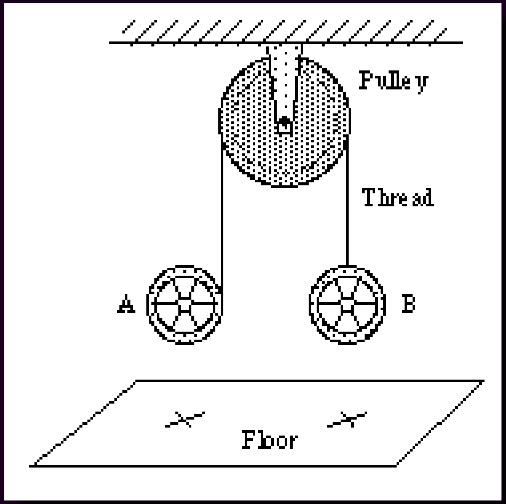
- perform an experiment with two spools of thread: one falls freely, the other is held by an unwinding thread as it falls
- observe that the freely falling one hits first
- conclude (we hope) that a force exerted on the edge of an object has an effect on the center-of-mass motion



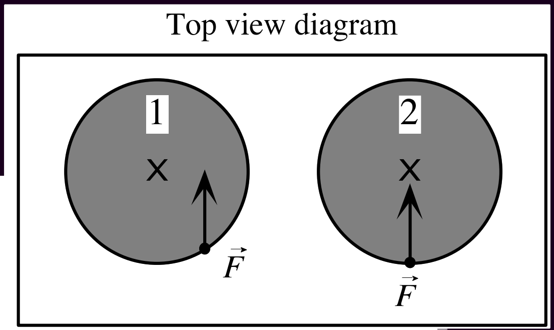
Further attempts to develop a tutorial

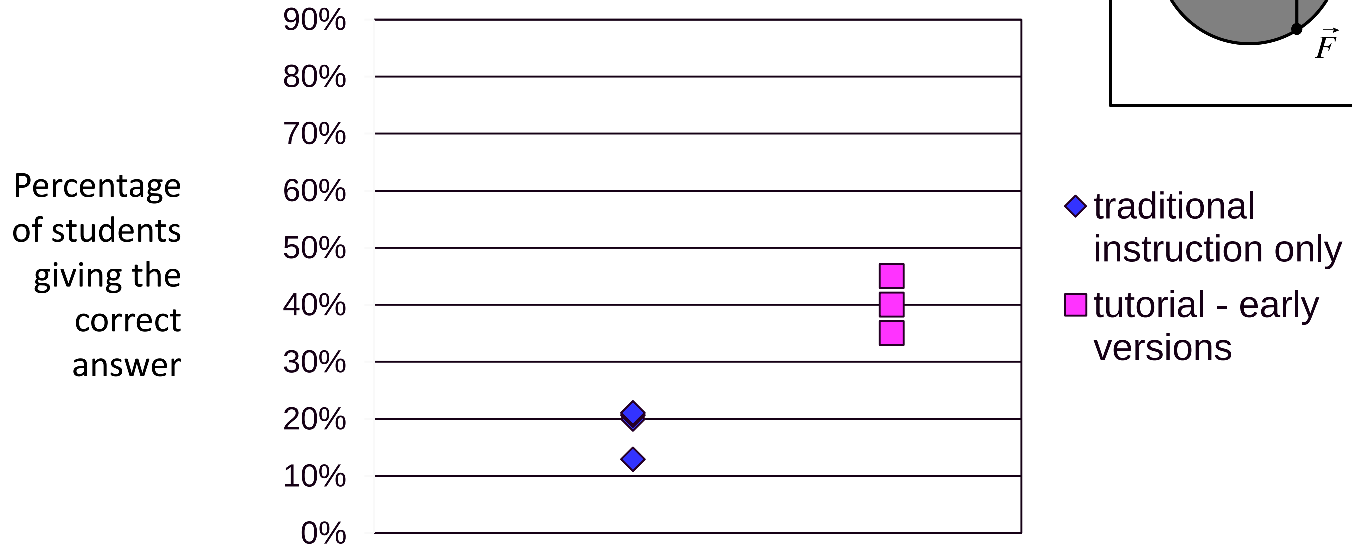
In later versions, students:

- perform an experiment with two spools that are connected by a thread that passes over a frictionless pulley: the thread is attached to one spool at its center but is wound around the other
- observe that the spools hit at the same time
- conclude (we hope) that a force exerted on the edge of an object has the **same effect** on center-of-mass motion as one exerted at the center



Two pucks question: Results



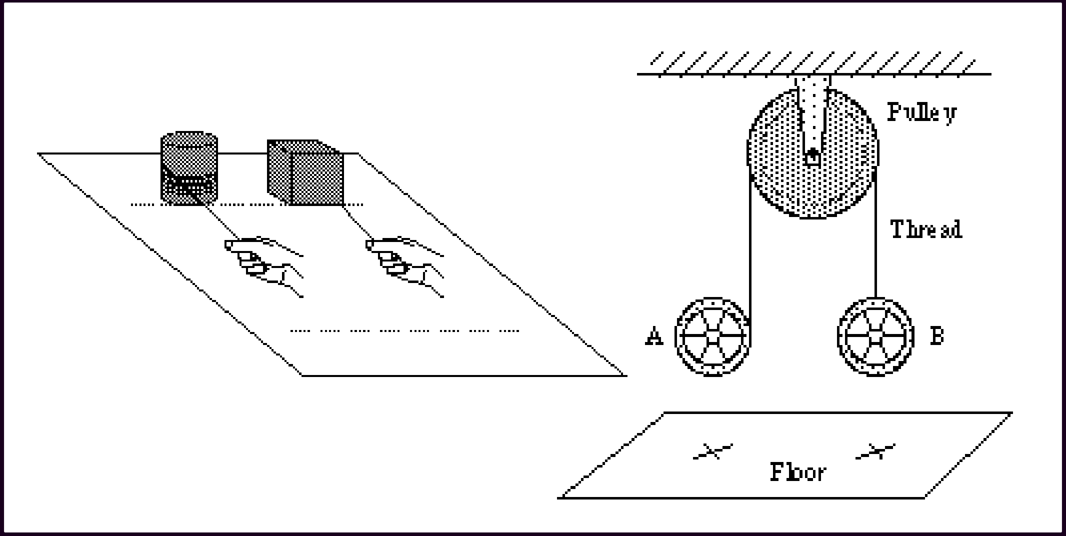


Close et al, AJP, 2013

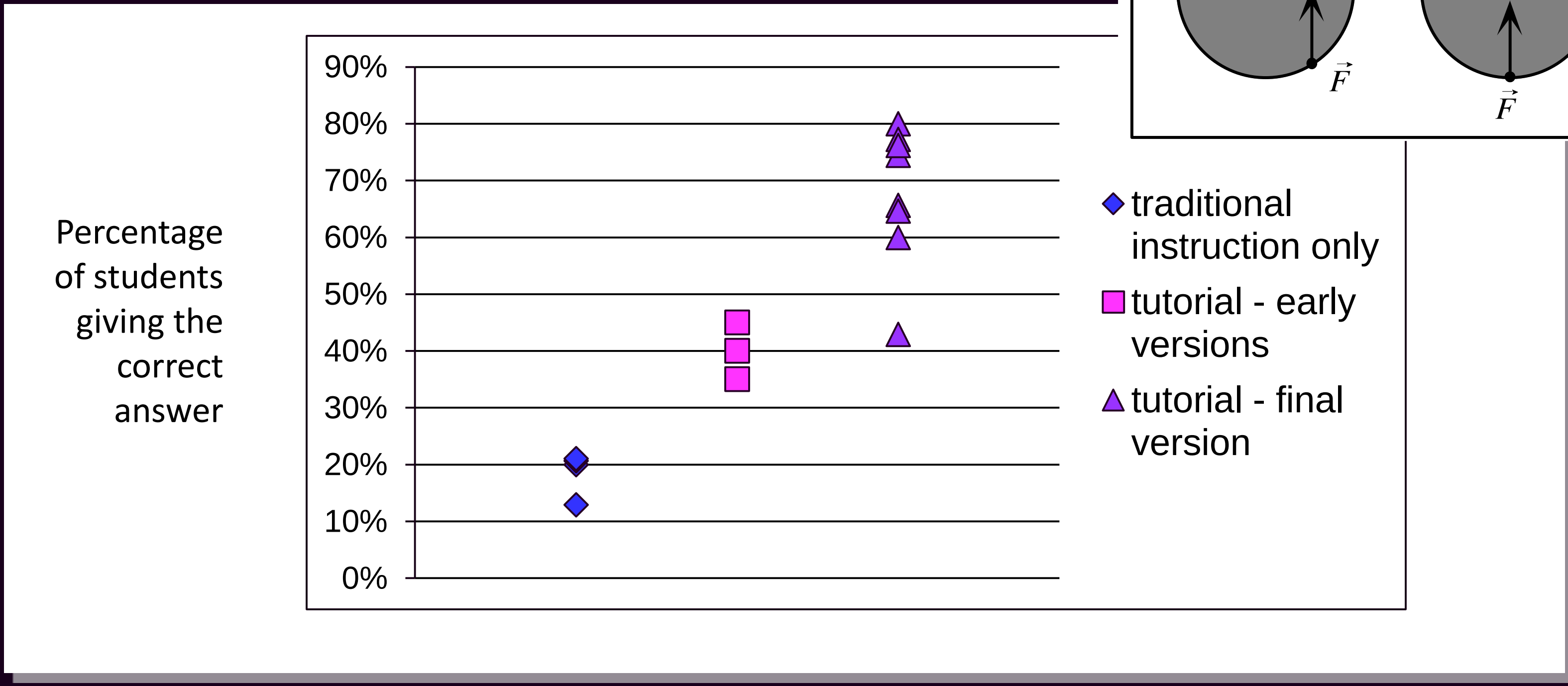
Even further attempts to develop a tutorial

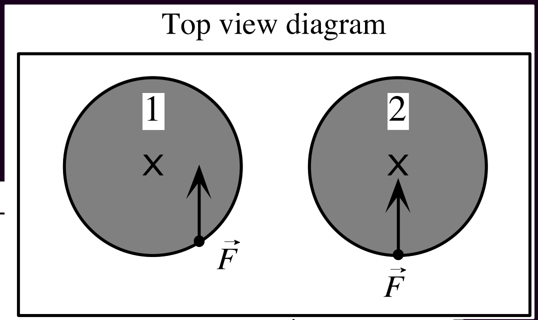
In the **current** version, students:

- consider a thought experiment about a block and a spool
- discuss predictions made by three hypothetical students
- consider the connected spools experiment
- decide what each hypothetical student would predict about the spools
- conduct the connected spools experiment, then revisit the block and spool experiment



Two pucks question: Results





Close et al, AJP, 2013

Even research-based instruction might not be effective.

Multiple cycles of assessment and redesign may be needed

Knowledge of student ideas in specific topic areas is essential for improving instruction.

Interactive instruction may be necessary, but it is not sufficient.

Instruction should be evidence-based, not ideology-based.

Physics Education Research

- is **not** about promoting a specific teaching method (and disparaging others).

- is **not** about dismissing knowledge of teaching and learning based on experience.

- **is** about promoting the view that systematically gathering and analyzing data is a good way to understand and affect complex phenomena.

Physics Education Research

Produces:

- Documentation of student difficulties with specific topics
- Generalizations about the student as a learner
- Generalizations about effective instructional strategies
- Effective instructional materials and strategies

Constitutes:

- A basis for objective, efficient, and cumulative improvement in instruction

Physics Education Research

Requires:

- Faculty, post-docs, and graduate students
  - with expertise in the subject matter
  - with access to the student population of interest
  - who devote their scholarly effort to examining teaching of their discipline

- Culture of peer review & publication of findings

Intellectual infrastructure centered in physics departments

Physics Education Research in the US

Official Statement on PER by the APS:

In recent years, physics education research has emerged as a topic of research within physics departments. This type of research is pursued in physics departments at several leading graduate and research institutions, it has attracted funding from major governmental agencies, it is both objective and experimental, it is developing and has developed publication and dissemination mechanisms, and Ph.D. students trained in the area are recruited to establish new programs. Physics education research can and should be subject to the same criteria for evaluation (papers published, grants, etc.) as research in other fields of physics. The outcome of this research will improve the methodology of teaching and teaching evaluation.

The APS applauds and supports the acceptance in physics departments of research in physics education. Much of the work done in this field is very specific to the teaching of physics and deals with the unique needs and demands of particular physics courses and the appropriate use of technology in those courses. The successful adaptation of physics education research to improve the state of teaching in any physics department requires close contact between the physics education researchers and the more traditional researchers who are also teachers. The APS recognizes that the success and usefulness of physics education research is greatly enhanced by its presence in the physics department.