Research in physics education: A resource for improving student learning

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New Physics and Astronomy
Faculty Workshop
June 2017

Physics Education Group at the University of Washington

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25 (1979-2017)

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Coordinated program of research, curriculum development, and instruction is supported, in part, by grants from the National Science Foundation.

Summary of workshop

- Overview of research and curriculum development by UW Physics Education Group
- Direct experience with curriculum (a *Tutorial* from *Tutorials in Introductory Physics*)
- Discussion of impact on student learning
- Generalizations on the teaching and learning of physics

Goals of UW Physics Education Group

- Conduct research on learning and teaching of physics concepts and reasoning (differs from traditional education research)

- Develop instructional procedures that:
  - are effective at helping students learn (concepts and reasoning)
  - yield similar results when used by faculty at other institutions

- Document impact and procedures in journals that are read by physics faculty (written in language accessible to physicists)
  - To help all faculty improve the effectiveness of instruction whether or not they are engaged in physics education research.

- Strengthen the preparation of K-12 teachers to teach physics and astronomy by inquiry

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Joint AAPT and APS resolutions (1999) encouraging physics departments to engage in:
(1) physics education research and (2) the preparation of K-12 teachers

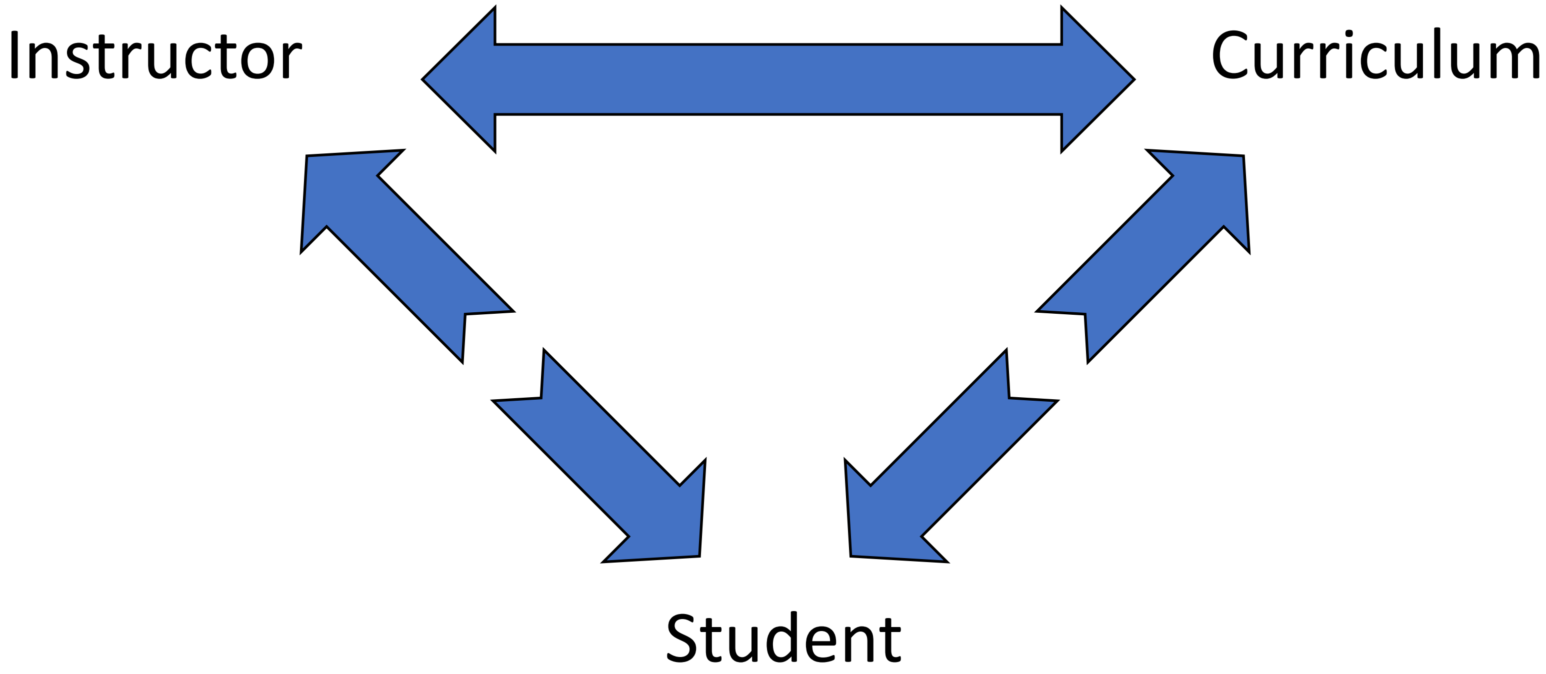
In working toward these goals, we have come to an important generalization:

On certain types of qualitative questions, student performance is essentially the same over a wide range of student ability:

- *before and after standard instruction*
- *in calculus-based and algebra-based courses*
- *with and without standard demonstrations*
- *with and without standard laboratory*
- *in large and small classes*
- *regardless of popularity of the instructor*

Hearing lectures, reading textbooks, seeing demonstrations, doing homework, and performing laboratory experiments often have little effect on student learning.

Evidence from research indicates gap



Gap greater than most instructors realize

- Teaching by telling is an ineffective mode of instruction for most students.

  Teaching by questioning can be more effective.

  Students must be intellectually active

Caution:

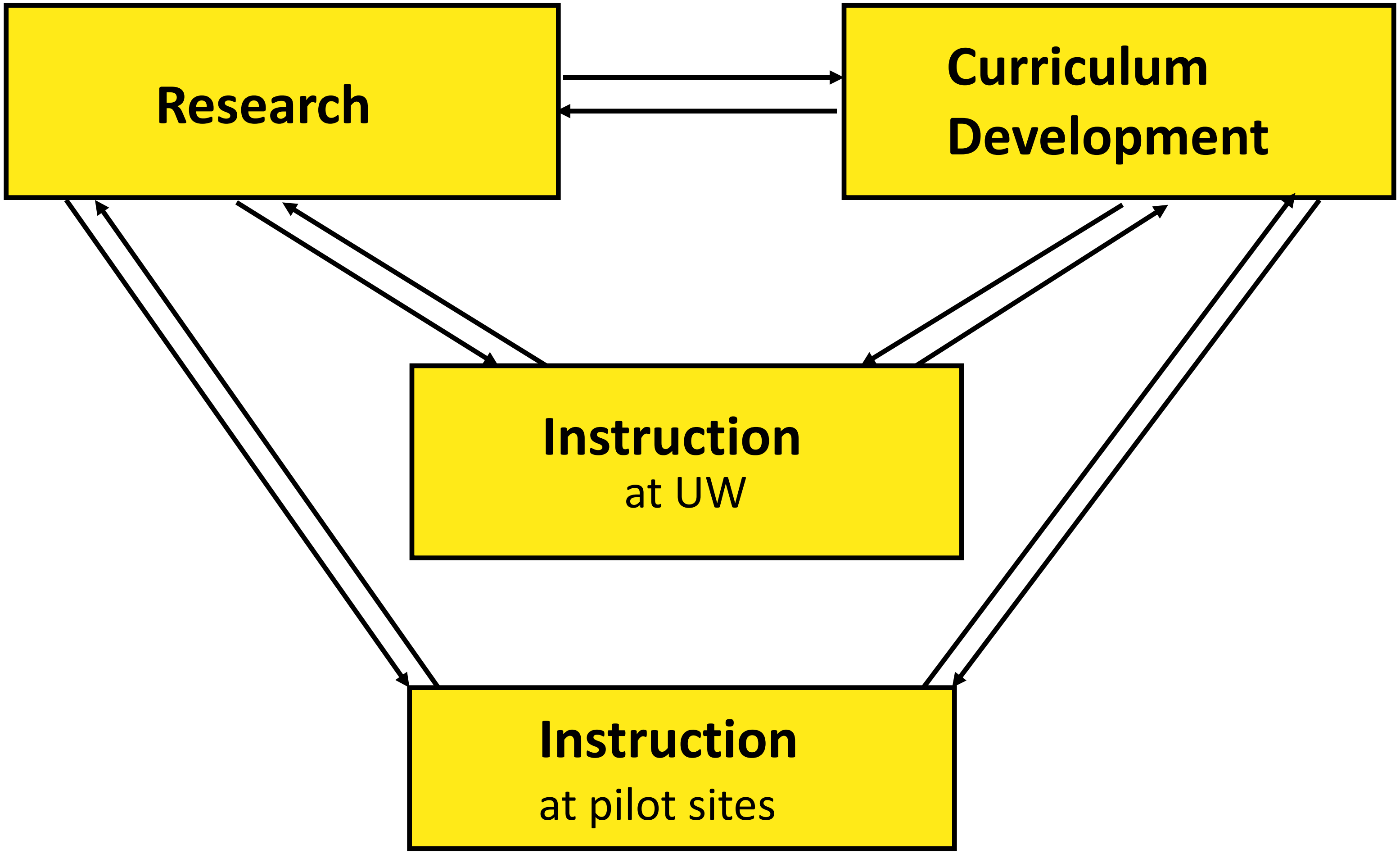
“active learning”
does not always lead to
“intellectual engagement”

Documented research is necessary
to determine the depth of understanding.

Systematic investigations of student learning (at the beginning, during, and after instruction)

- **individual demonstration interviews**
  - for probing student understanding in depth
- **written questions with explanations** (pretests and post-tests)
  - for ascertaining prevalence of specific difficulties
  - for assessing effectiveness of instruction
- **descriptive studies during instruction**
  - for providing insights to guide curriculum development

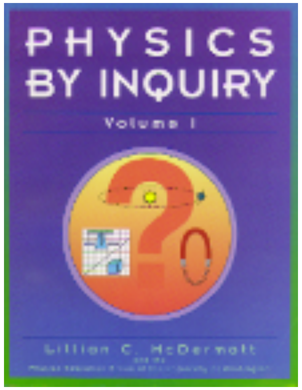
Application of research to development of curriculum



Research-based ≠ Research-validated

Research-based curriculum development

Preparing precollege teachers to teach physics and physical science

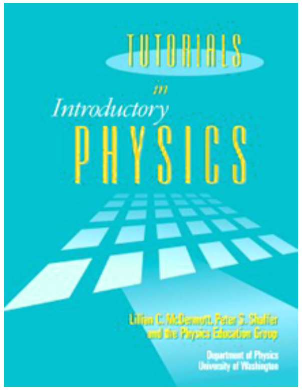


– Physics by Inquiry –

(John Wiley & Sons, Inc., 1996)

Self-contained, laboratory-based, no lectures

Improving student learning in introductory physics



– Tutorials in Introductory Physics –

(Prentice Hall, 2002)

Supplementary to lecture-based course

Tutorials respond to the research question:

Is standard presentation of a basic topic in textbook or lecture adequate to develop a *functional understanding*?

(*i.e.,* the ability to do the reasoning necessary to apply relevant concepts and principles in situations not explicitly studied)

If not,

what needs to be done?

Emphasis in tutorials is

on

- constructing concepts
- developing reasoning ability
- relating physics formalism to real world

<u>not</u> on

- solving standard quantitative problems

Primary context (at UW) for tutorials

Each week:

- 3 lectures (50 minutes)
- 1 laboratory (2-3 hours)
- 1 tutorial (50 minutes)

However, use can vary (*e.g.,* in lectures or labs)
depending on constraints like
class size, room availability, number of lecturers,

number of TAs or peer-instructors, *etc.*

Tutorial Components

- **weekly pretests**
  - *given usually after lecture on relevant material but before tutorial*
- **tutorial sessions**
  - *small groups (3-4) work through carefully structured **worksheets***
  - *tutorial instructors question students in semi-Socratic manner*
- **tutorial homework**

Additional critical components

- **examination questions**
  - *all exams include tutorial post-test questions (to help ensure students take seriously the focus on understanding emphasized in tutorial)*
- **required weekly seminar for tutorial instructors**
  - *TA's, peer instructors, etc.*
  - *preparation in content and instructional method*
  - *TAs take pretest, work through tutorial, and discuss student responses.*

Example of tutorial: *Dynamics of rigid bodies*

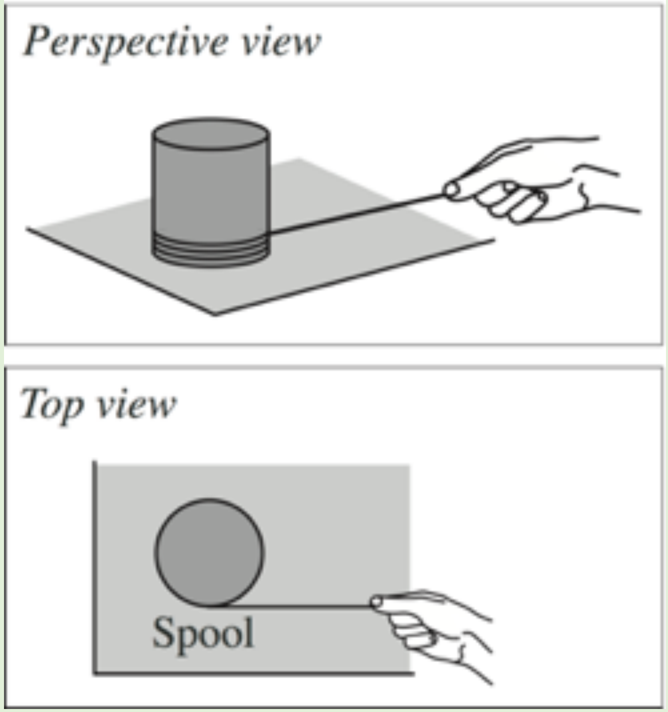
- Pretest
  - Please complete on your own; take no more than about 5 minutes to answer.

- Tutorial
  - Please work in small groups
  - There will be full-workshop discussions (not typical of small group tutorial sessions*)

  **** Similar in structure to TA preparation sessions***

- Assessment of tutorial and generalizations

Dynamics of rigid bodies, page 1



A spool is pulled across a frictionless table as shown. The hand pulls horizontally. The thread has been wrapped many times around the bottom of the spool.

- ***Predict*** whether the spool will rotate. Explain.
- ***Predict*** whether the center of the spool will move and if so, in which direction. Explain.

Test your answers by performing the experiment on a table *with* friction.

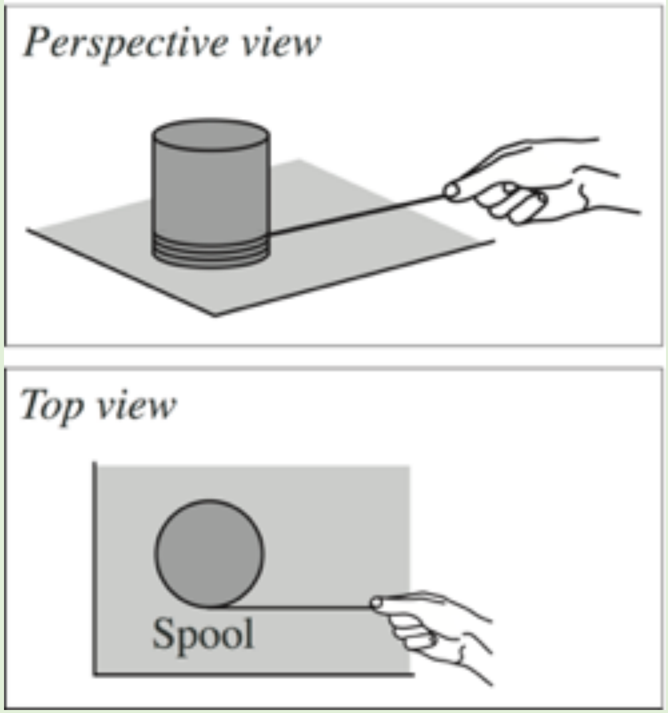
What do your answers suggest about what would happen if the table were frictionless?

observe video (as a group).

As instructors, think about answers that students might give to these tasks and what it might indicate about their thinking.

Spool on air table (negligible friction)

Dynamics of rigid bodies, page 1



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Examples of student responses to spools question from page 1 (when given as pretest)

The spool will rotate and not translate

- "The force of the string will cause torque. ... There is no force ***applied directly to the spool*** to make it go forward."

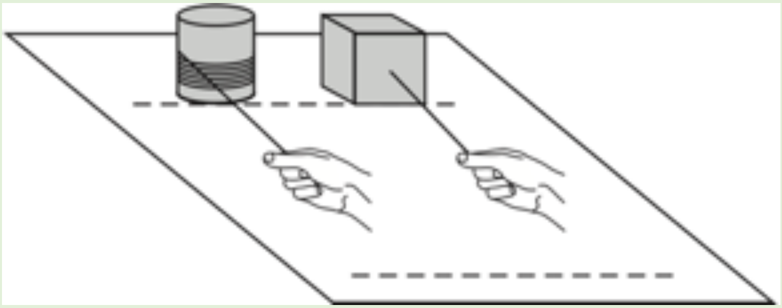
Force not at center of mass results in rotation only.

The spool will translate and not rotate

- "There is no friction due to the surface so the … particles on the other side [of the spool] have no force keeping it put - so the spool will not rotate."
- "on a frictionless surface. The tension will not generate rotation because there is no force acting in the opposite direction to generate rotation. … for rotation to begin, there must be a force acting in the positive and negative direction on the spool and in this case, there is no negative force."

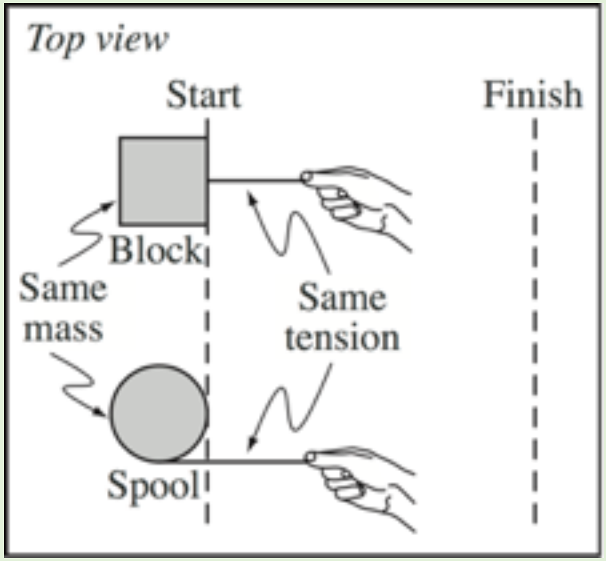
Force not at center of mass results only in translation of entire object unless another force acts to rotate object

Dynamics of rigid bodies, page 2



A block and spool are each pulled across a level, frictionless surface by a string.

- ***Predict*** the order in which they cross the finish line.

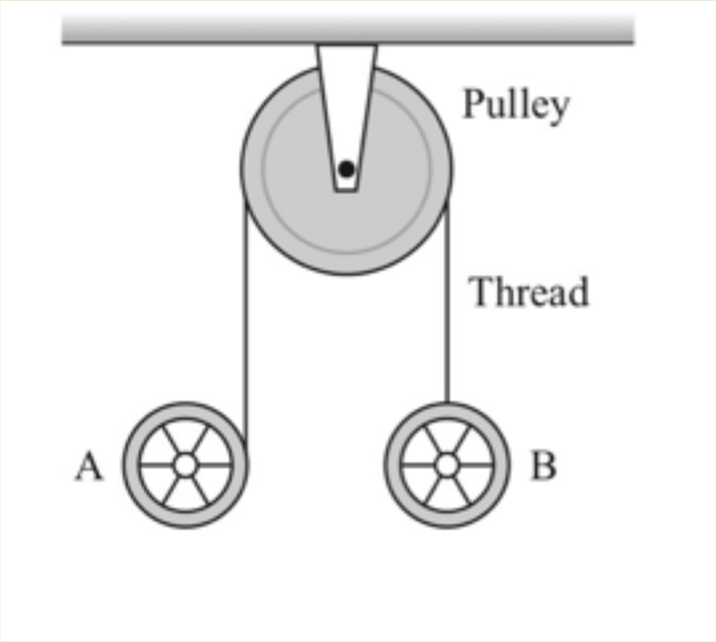


- Three students discuss the experiment.
  1. The spool rotates and **both finish at the same time** … same mass and net force so the centers have the same acceleration. The tensions have the same effect on translational motion.
  2. The **spool crosses after the block**. Some tension is used to rotate the spool. When a force causes rotation, it has less effect on translation.
  3. I agree the spool rotates and crosses later, but I was thinking about **energy**. They have the same total kinetic energy at the finish line. Since the spool has some rotational KE, it must have less translational KE.

With which student do you agree?

Continue to page 3 when you and your partners are ready.

Dynamics of rigid bodies, page 3



Two identical spools are connected by a thread that runs over an ideal pulley. The thread is wrapped around spool A many time, but is attached to a fixed point on spool B.

The spools are released from the same height at the same time.

- *Predict* whether spool A will hit the floor *before, after,* or *at the same time as* spool B.

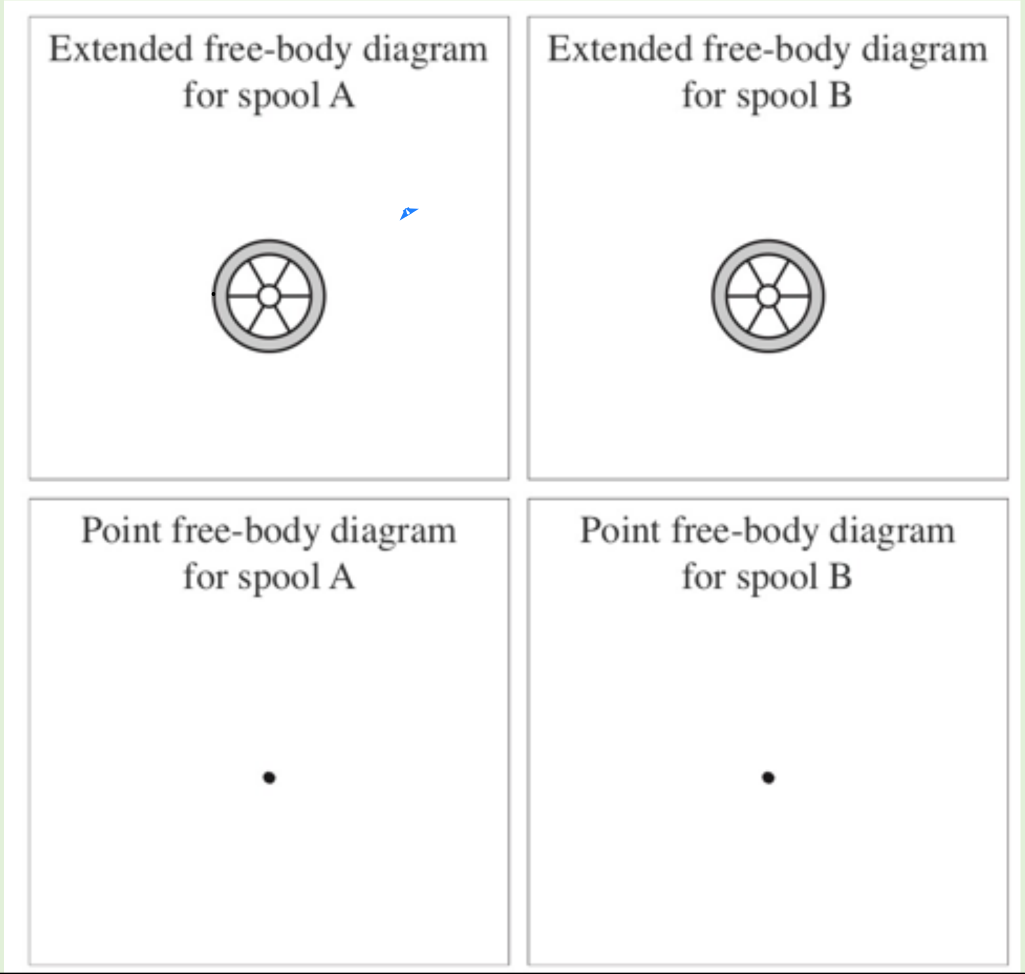
- Draw the following diagrams for each spool, corresponding to a time shortly after they are released:
  - an extended free-body diagram
  - a (point) free-body diagram

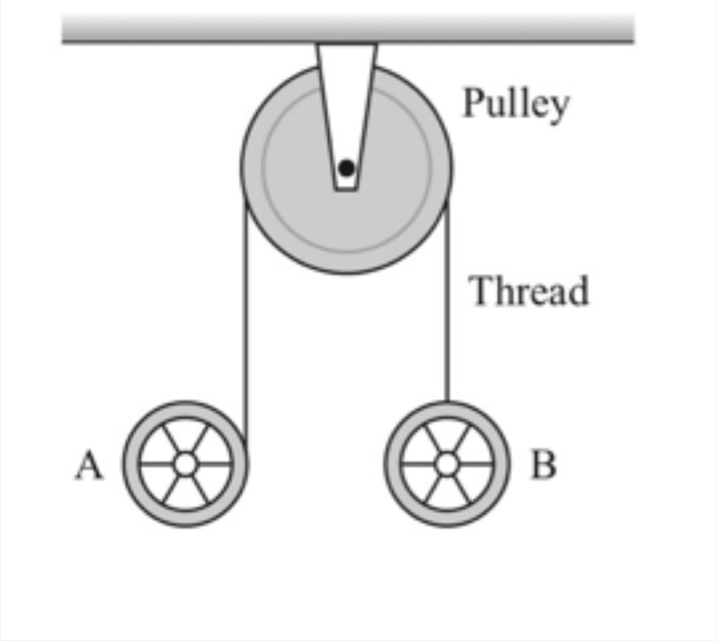
- What would each student on the previous page predict?

We will discuss the answers and observe a video as group.

Dynamics of rigid bodies, page 3

- Draw for each spool:
  - an extended free-body diagram
  - a (point) free-body diagram





Dynamics of rigid bodies, page 3

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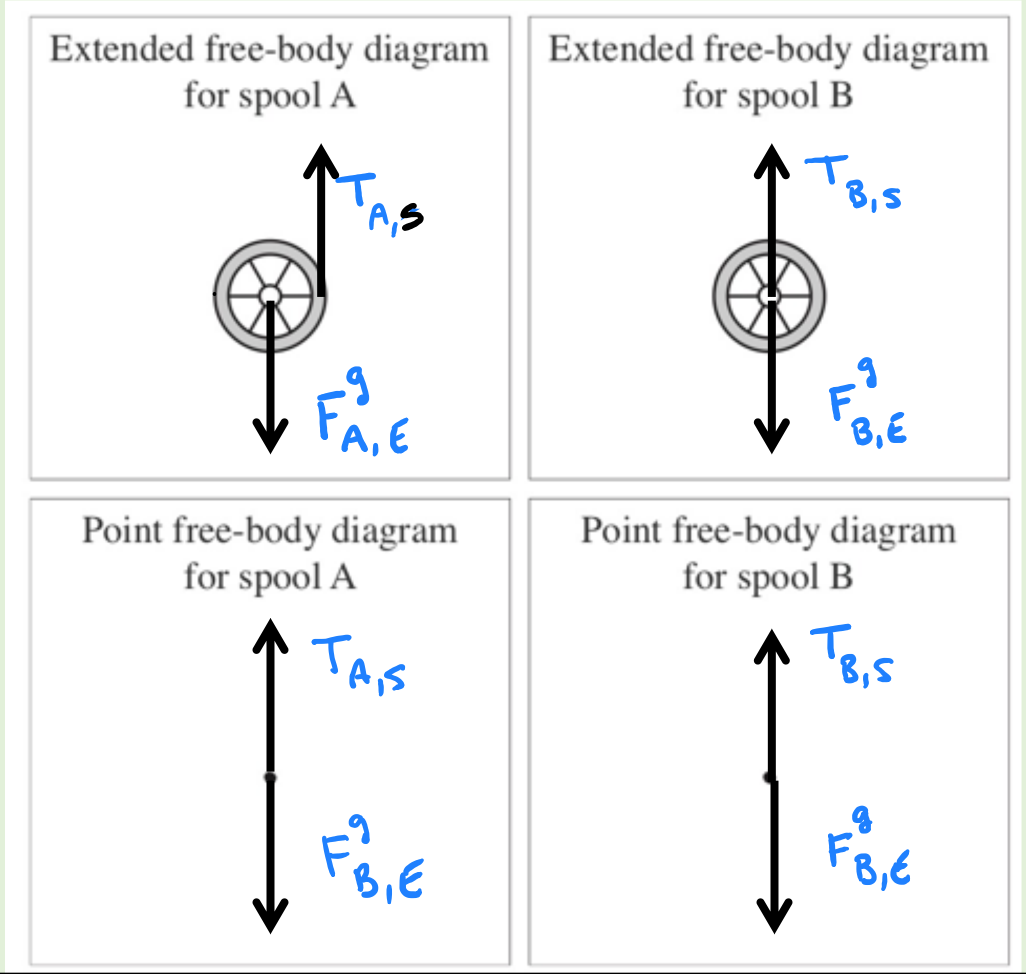
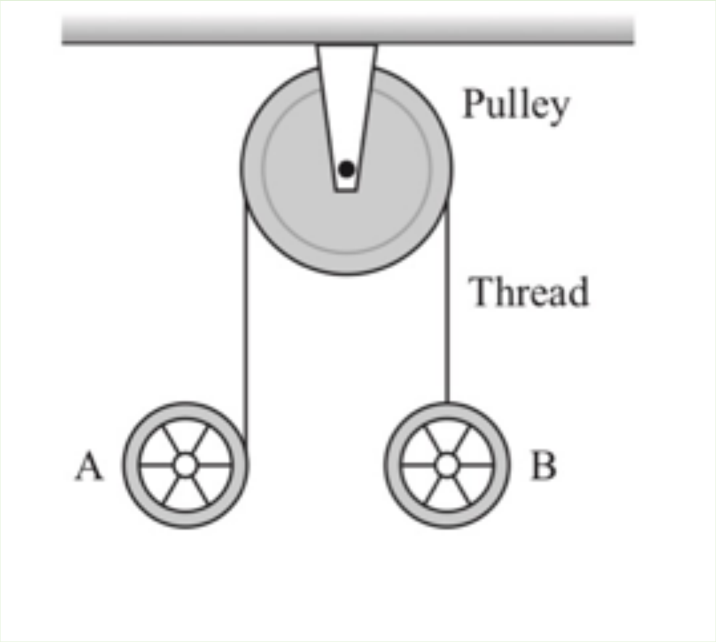
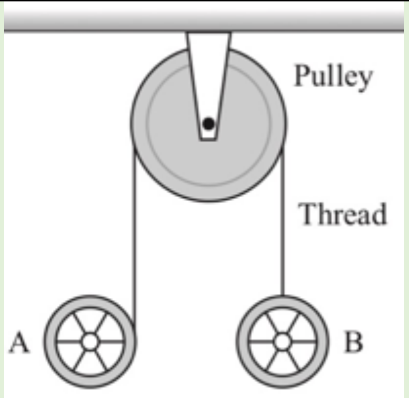




Dynamics of rigid bodies, page 3



- What would each student on the previous page predict?

1. They have the same mass and same net force so the centers of mass have the same acceleration. The tensions have the same effect on translational motion.

    Same forces, same mass → **A lands at same time as B**

2. Some tension is used to rotate the spool. When a force causes rotation, it has less effect on translation.

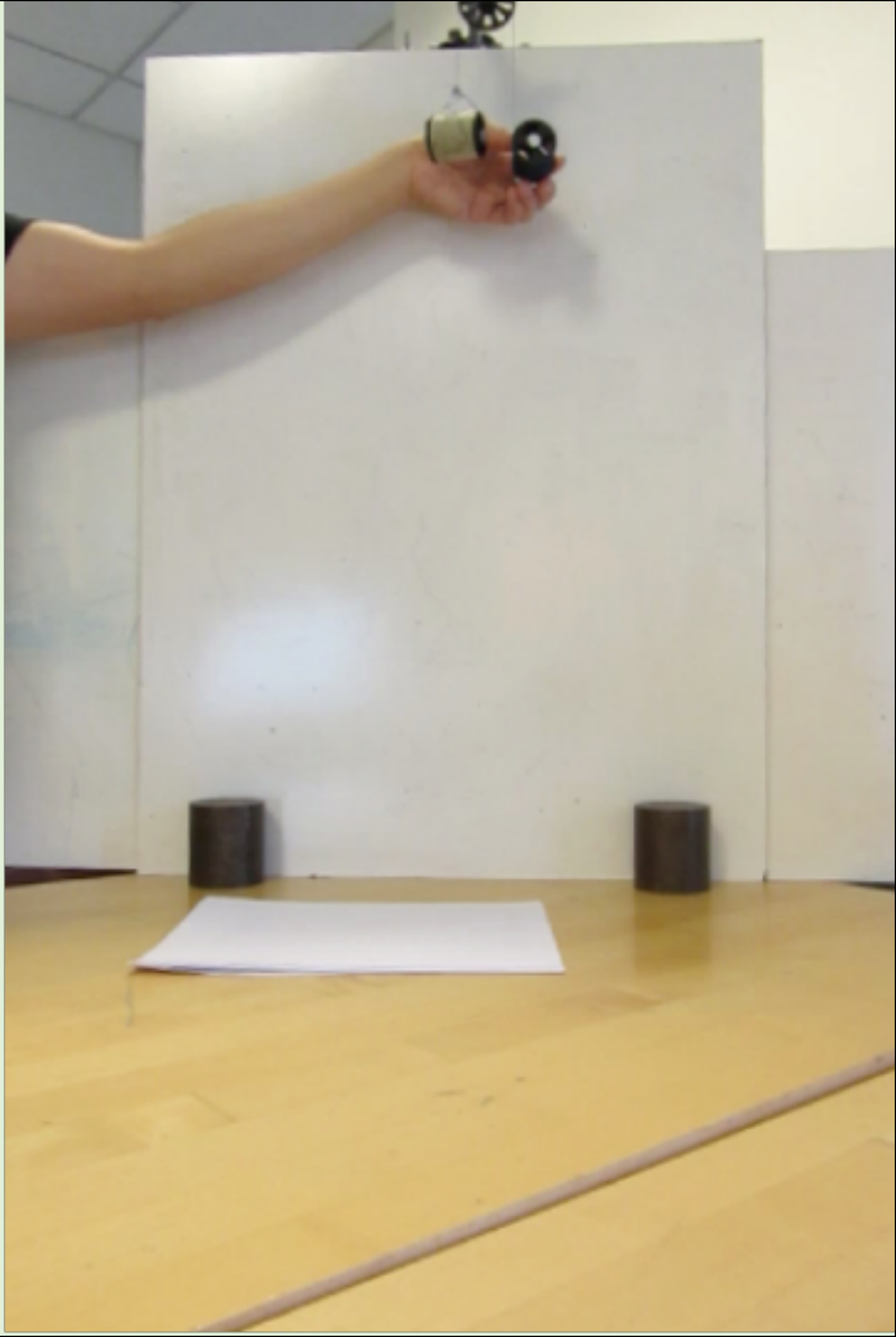
    T has less effect on A so A has larger net force down → **A lands before B**

3. I was thinking about energy. They have the same total kinetic energy at the finish line. Since the spool has some rotational KE, it must have less translational KE.

    Same total energy, A has rotational and kinetic → **A lands after B**

Three different predictions

Spools connected by string



Dynamics of rigid bodies, page 4

F. Suppose you want to consider how a force affects the translational motion of the center of mass of an object. Should you consider:

- where on the object the force is exerted?

- how the force is affecting the rotational motion of the object?

In the *Tutorial homework,* students reconcile their results with work and energy

Assessments of student learning

- "Pretests"
  - Questions administered after all instruction through lecture and textbook but before students had worked through tutorial.
    - Provide motivation for the tutorials and insights into student reasoning that guided development
- "Post-tests"
  - Questions administered after all instruction including *Tutorial* and *Tutorial Homework. Typically somewhat more difficult than pretests.*

Note: Results are typically within about 5% from class to class,

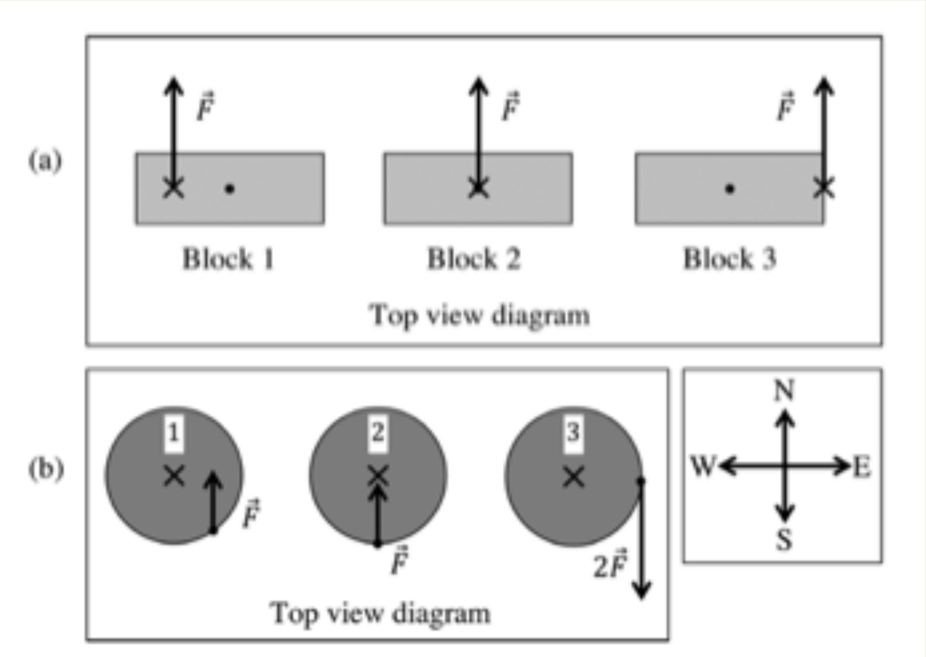
independent of instructor or textbook.

Thus, results from multiple classes are combined.

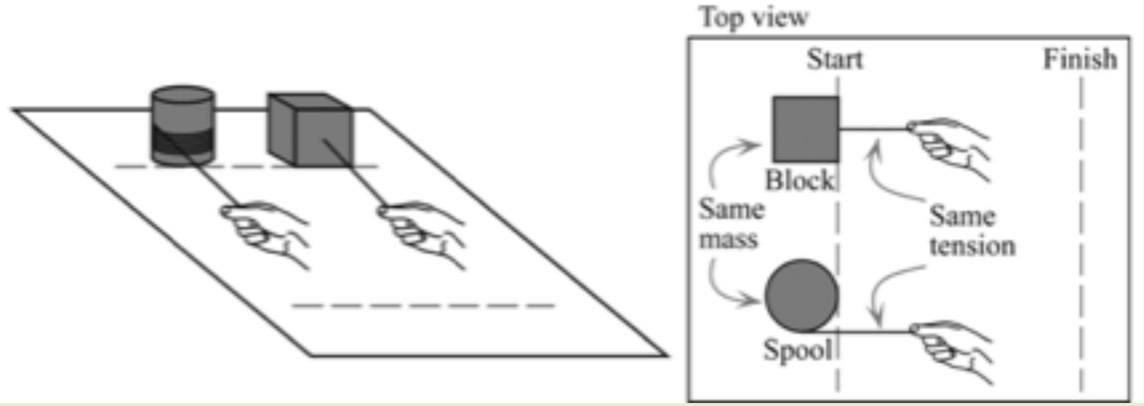
"Student understanding of the application of Newton's second law to rotating rigid bodies," H.G. Close, L.S. Ortiz, and P.R.L. Heron, *Am. J. Phys.* **81** (6) 2013

Examples of Pretests

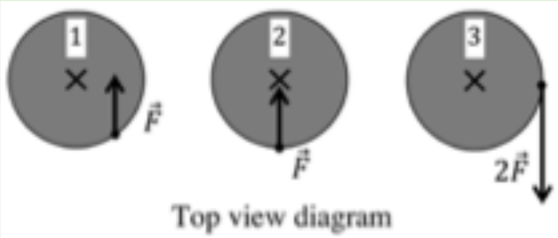
- Students asked to compare center-of-mass accelerations (directions and magnitudes) of the blocks or pucks at the instants shown.

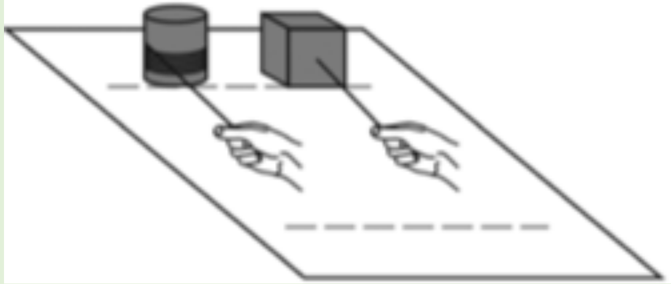


- Students asked about the order in which the objects would cross the Finish line.



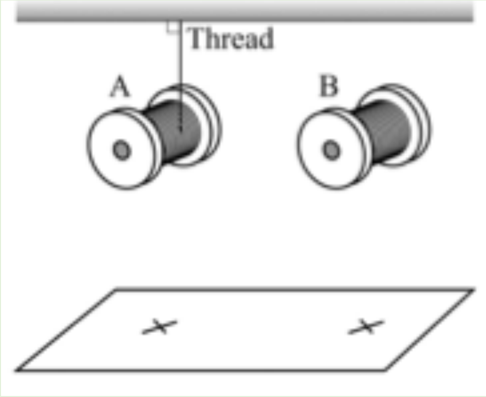
Results from Pretests





	Pucks	Block-and-spool
Correct (equal acceleration / same time)	20%	~ 5%
Treating a force as having less effect on translation if it also results in a rotation	65%	60%
Belief that a force applied at the edge of an object causes only rotation	N/A	20%

Analysis of results guided design of tutorial over several years



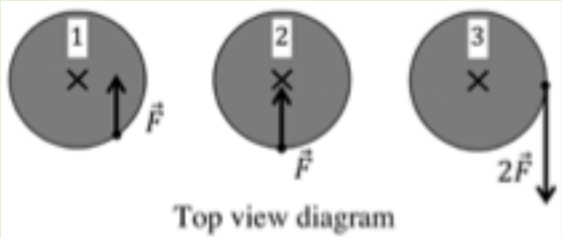
- Version 1:
  - ‘Unconnected spools’
  - Student dialogue (but without having students apply each student’s reasoning to new case)

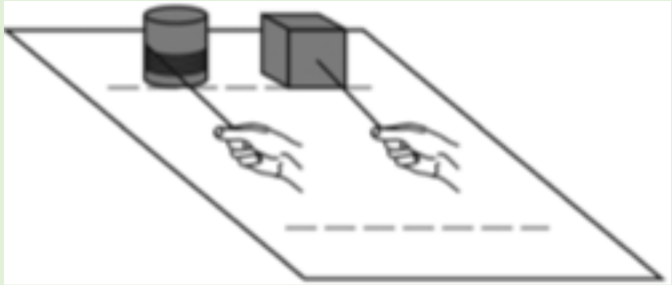
  Some improvement: From 20% to 40% correct

- Versions 2 &is 3 led to small gains
  - Results, however, indicated students held very strongly to the idea that the effect of a force on translation is decreased if the force also causes rotation.
  - Note: They can believe this and still answer the ‘unconnected spools’ question correctly.

- Version 4: The ‘connected spools’ experiment was developed to target this idea directly (since the forces on both spools are the same).

Results from Post-tests





	Pucks		Block-and-spool	
	Pretest	Post-test	Pretest	Post-test
Correct (Equal acceleration / same time)	20%	70%	5%	80%

Practical criterion for effectiveness of a tutorial:

Post-test performance of introductory students
matches (or surpasses)
pretest performance of graduate students.

(TAs were about 30% correct on circular pucks question)

Generalization based on findings from research:

It is insufficient for the instructor to

- give clear explanations
- show demonstrations
- assign problems and provide solutions
- be informed about student difficulties

Active mental engagement
by the students, themselves, is necessary.

Assessments of student learning at UW and beyond on many topics

Effect of tutorials on student performance

On qualitative problems:

- *much better*

On quantitative problems (e.g., end of chapter):

- typically somewhat better
- sometimes much better

On retention:

- sometimes much better

despite less time devoted to solving standard problems

The tutorials are <u>one</u> example of how, with a small time allotment, a research-based curriculum can help:

- make physics meaningful to students
- provide a foundation for quantitative problem solving
- develop scientific reasoning ability

even under constraints of large class size,
breadth of coverage, fast pace, limited time

The perspective that teaching is a science, as well as an art, is an effective approach for:

- setting high (yet realistic) standards
- assessing the extent to which meaningful learning takes place
- helping students meet expectations