The use of guided questioning to promote student learning:
Introduction to Tutorials in Introductory Physics

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New Physics and Astronomy
Faculty Workshop
October 2018

Welcome to this workshop

An important objective of this workshop

Demonstrate how research on the learning and teaching of physics can help (and has helped) improve the effectiveness of instruction.

Physics Education Group at the University of Washington

Faculty

Lillian C. McDermott
Paula Heron
Peter Shaffer
Suzanne White Brahmia

Lecturers & Post-docs

Donna Messina (K-12 teacher)
Alexis Olsho

Physics Ph.D. Graduates

28 (1979-2018)

Physics Ph.D. Students

Anne Alesandrini
Dean Bretland
Sheh Lit Chang
Kevin Cutler
Lisa Goodhew
Bert Xue
Charlotte Zimmerman

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

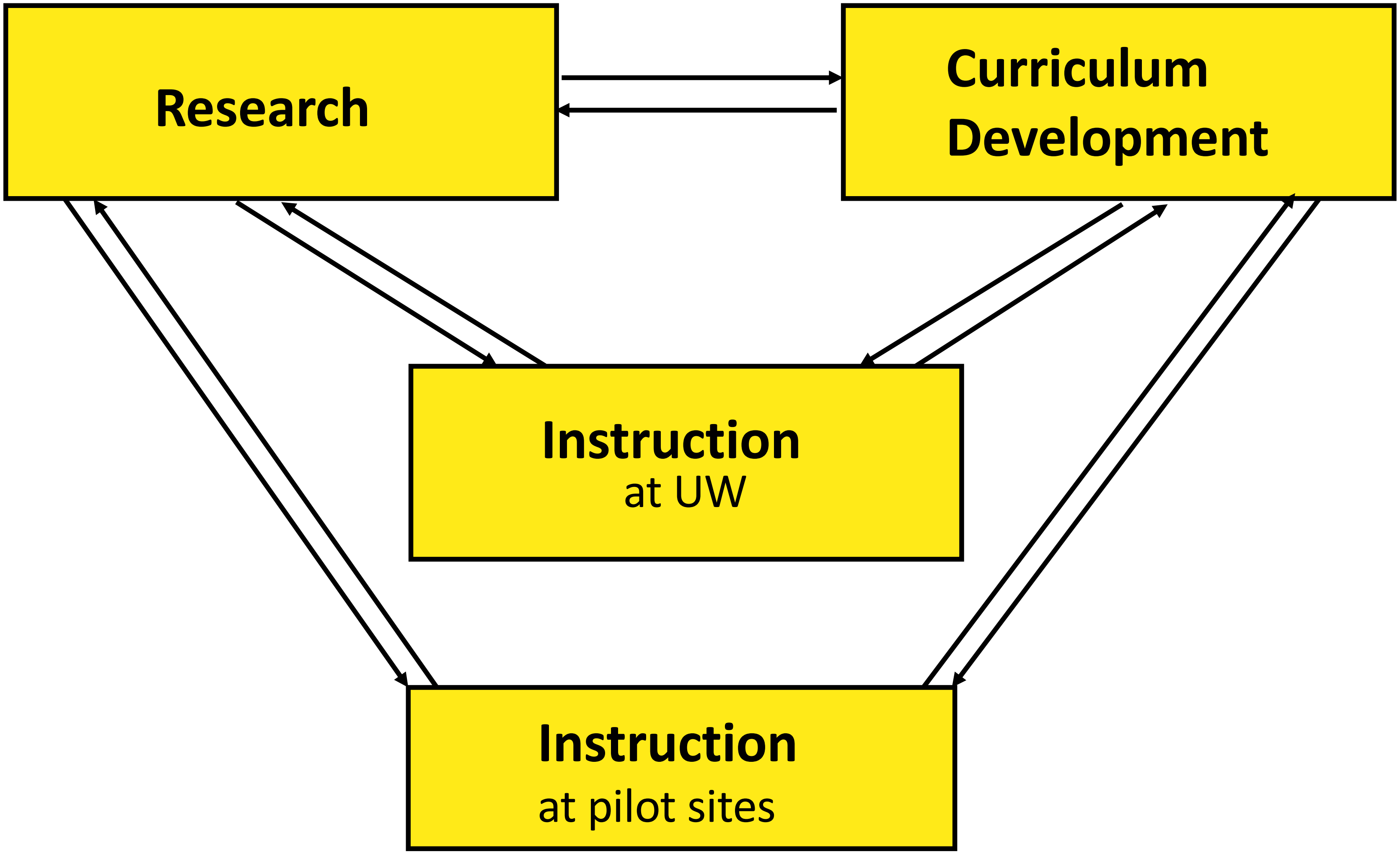
Goals and procedures of UW Physics Education Group

- Conduct research on learning and teaching of physics concepts and reasoning
  - In depth (interviews)
  - large scale (written questions requiring explanations)
  - classroom observations (and interactions with students)

- Develop instructional procedures that:
  - are effective at helping students learn (concepts and reasoning)
  - yield similar results when used by faculty at other institutions
  - prepare K-12 Teachers to teach physics by inquiry, not by lecture

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

Application of research to development of curriculum

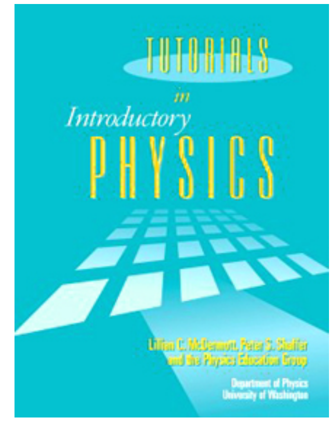


Research-based ≠ Research-validated

Research-based curriculum development

Improving student learning in

- Introductory physics



* *Tutorials in Introductory Physics*
(Prentice Hall, 2002)
Supplementary to lecture-based course

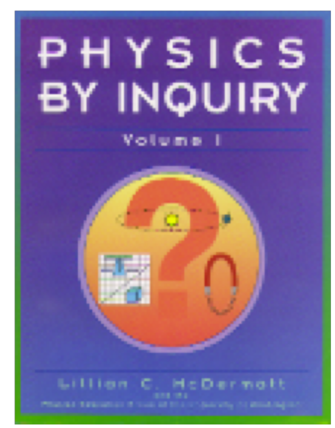
- **Advanced physics** (E&M and Quantum Mechanics)

Preparing K-12 teachers to teach physics & physical science by inquiry and to be able to help their students think critically

* *Physics by Inquiry*

(John Wiley & Sons, Inc., 1996)

Self-contained, laboratory-based, no lectures



Summary of workshop

- Brief overview of research and curriculum development by UW Physics Education Group
- Direct experience by workshop participants with a *Tutorial* (modified slightly)
- Overview of impact on student learning
- Discussion on use of guided questioning in teaching physics

In this workshop, emphasis is on introductory course:
Tutorials in Introductory Physics

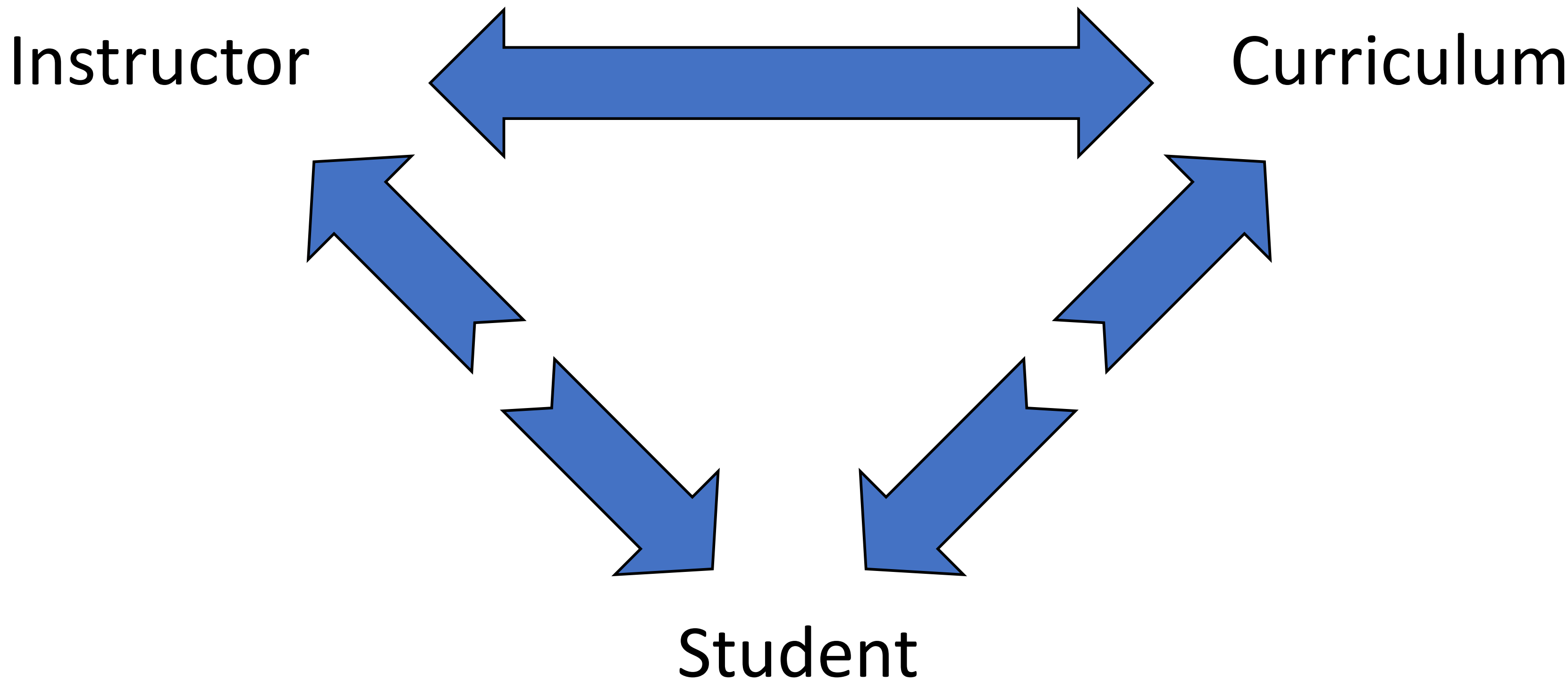
Motivation for use of guided questioning in teaching physics

Physics education research has demonstrated that 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 reveals gap



Gap greater than most instructors realize

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

  Students must be intellectually active.

Teaching by questioning can be more effective, but the kinds of questions matter.

Research can help identify sequences of questions that are effective.

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 can be done?

In particular, what is possible in a typical introductory physics course with usual constraints?

Tutorial components

- **Pretests** (~15 minutes)
  - *Usually given <u>after</u> lecture on relevant material but before tutorial*
- **Tutorial sessions** (~ 50 minutes)
  - *Small groups (3-4) work through carefully structured* ***worksheets***
  - *Tutorial instructors question students in semi-Socratic manner*
- **Tutorial homework** (written questions take students < 1 hr/wk)

Additional critical components

- **One or more questions on exams based on tutorials (w/explanations)**
  - *So students take seriously the emphasis on understanding*
- **Required weekly preparation for tutorial instructors**
  - *Graduate and undergraduate TAs work through tutorials with questioning by experienced instructor*

Example of a *Tutorial: Dynamics of rigid bodies*

- Pretest
  - Please complete on your own; take no more than about 3 minutes to answer. (Students would have more time.)

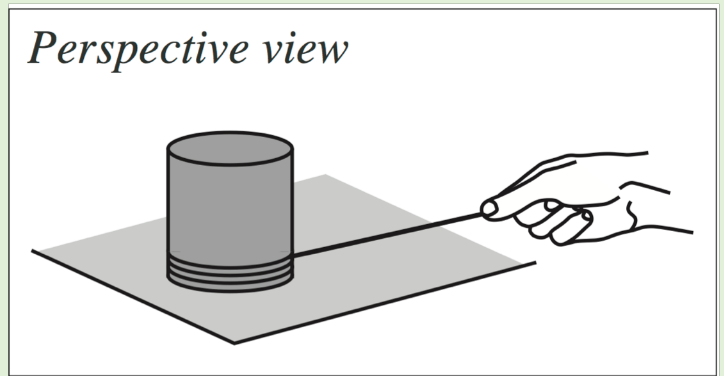
- Tutorial
  - Work in small groups followed by full-workshop discussions
    (Full group discussions not typical of student tutorial sessions)

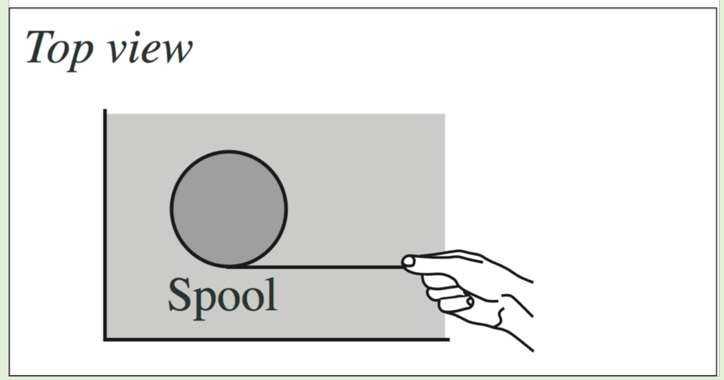
- Discussion of impact of tutorial and generalizations on method

Small group activity: page 1, Part A

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.





As instructors, discuss answers that students might give and what the answers might indicate about student thinking.

Large group activity (Parts B and C)

Students would test their answers by observing the experiment on a table *with* friction.

Students would consider what their observations suggest would happen if the table were frictionless.

Spool on various tables (varying friction)

Examples of student responses to spools question from page 1 (*e.g.,* when given as pretest)

The spool will <u>rotate and not translate</u>

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

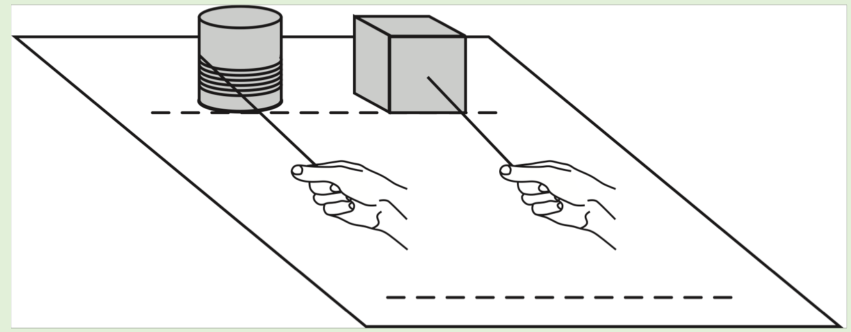
➡ ***Belief that force not at center of mass results in rotation only.***

The spool will <u>translate and not rotate</u>

- "There is no friction so the … particles on the other side [of the spool] have no force keeping it put - so the spool will not rotate."

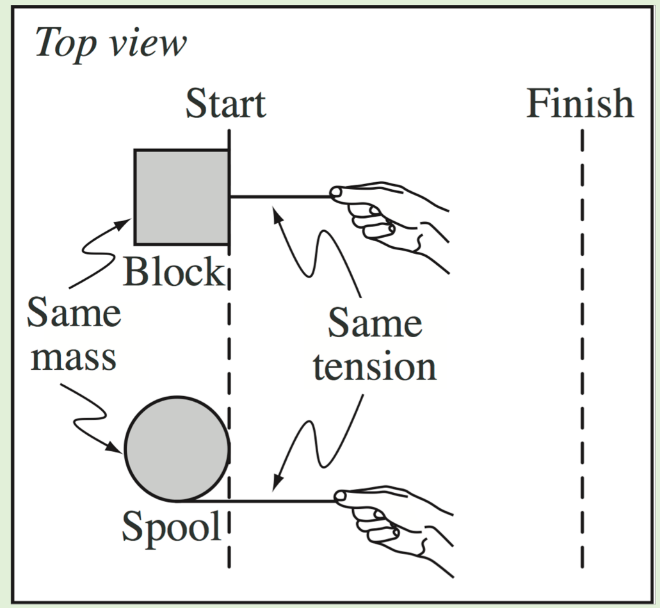
➡ ***Belief that force not at center of mass results only in translation of entire object -- unless another force acts to rotate object***

Small group activity: 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. "I disagree. 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."

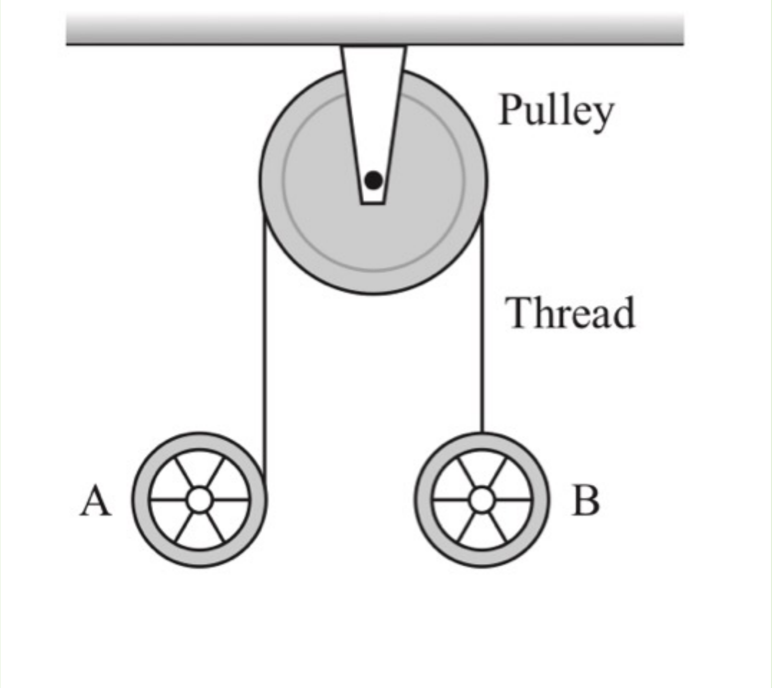
With which student do you agree?

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

Small group activity: page 3

Two identical spools are connected by a thread that runs over an ideal pulley. The thread is wrapped around spool A many times, 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.**

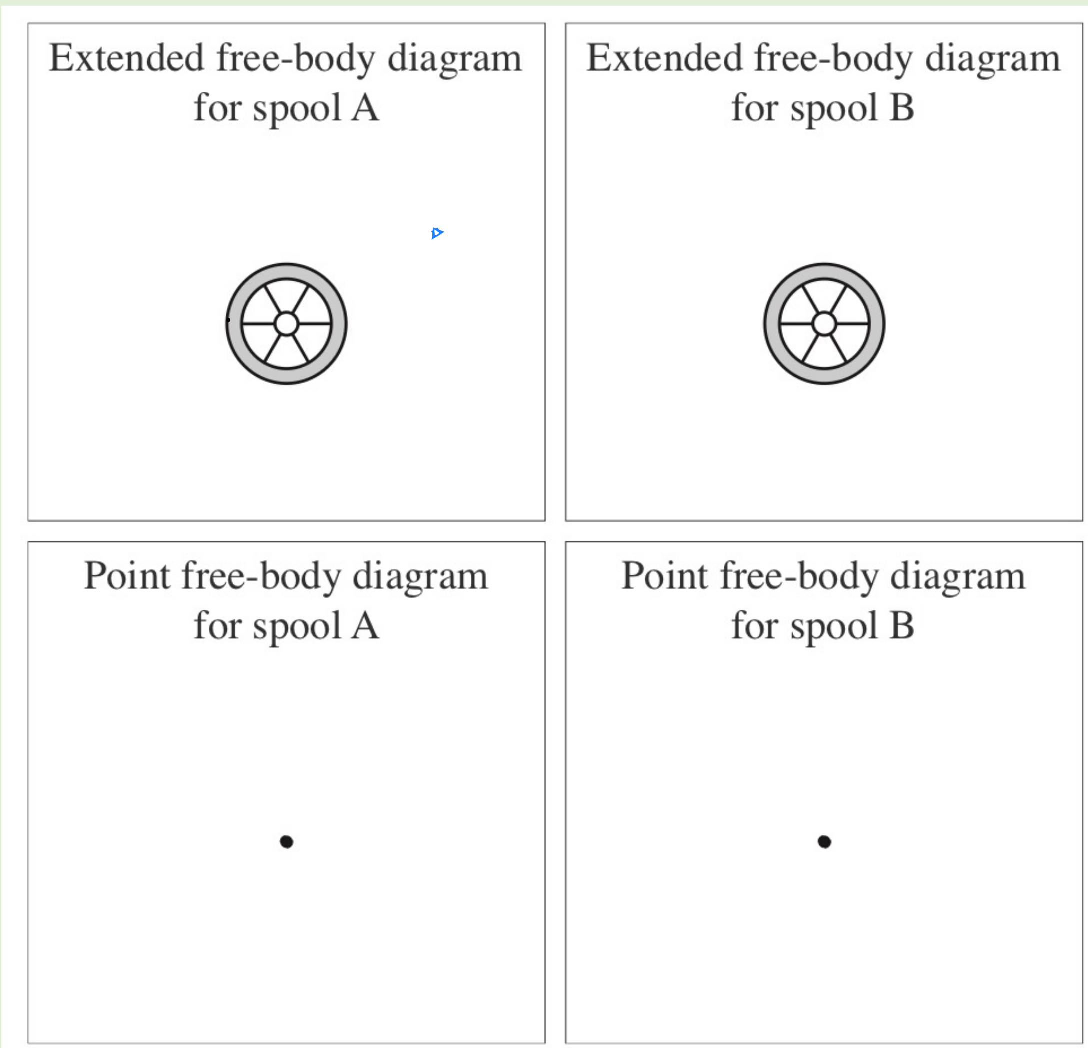
- **Draw the following diagrams for each spool,** corresponding to a time shortly after release:
  - an extended free-body diagram
  - a (point) free-body diagram

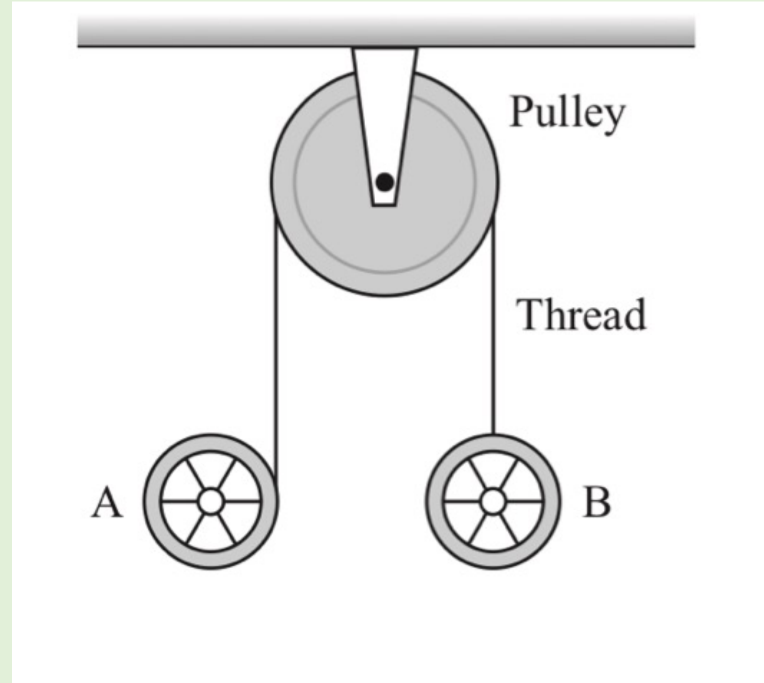
- What would each student on the previous page predict?

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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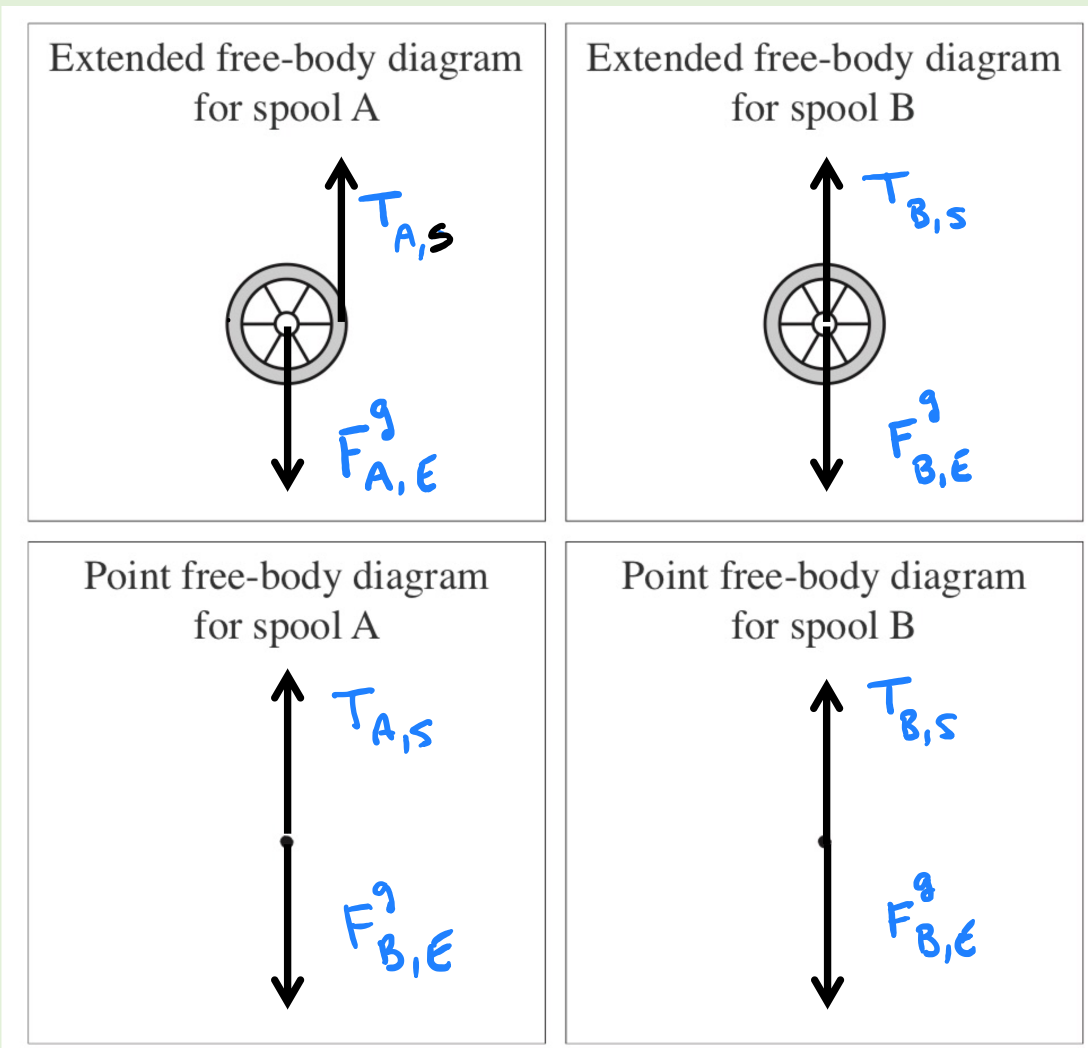
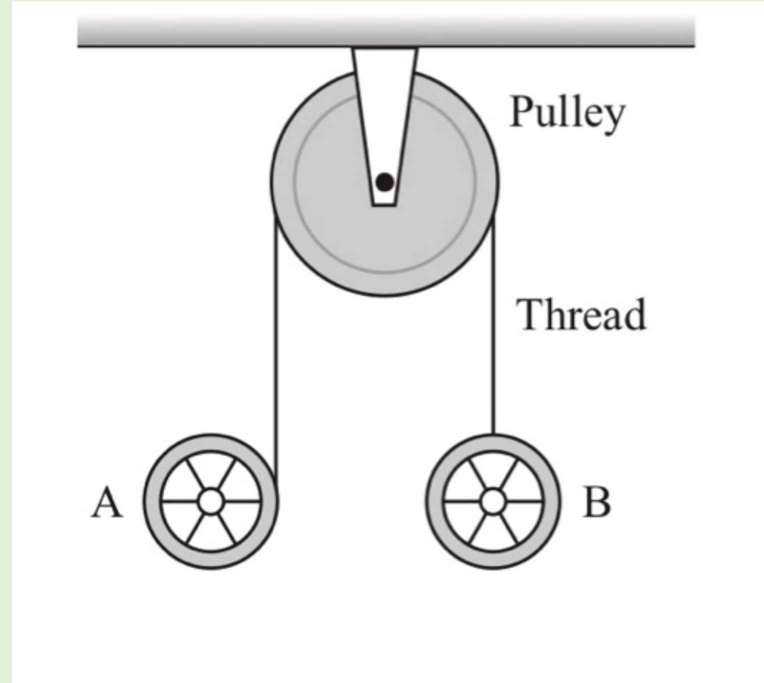
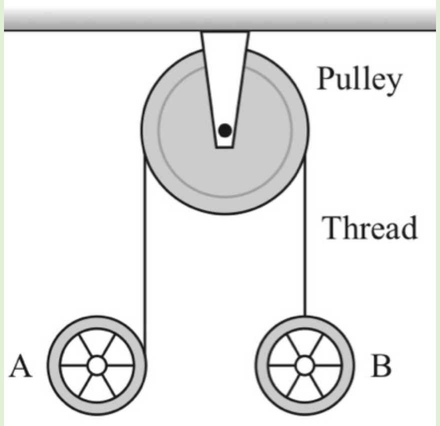




Dynamics of rigid bodies, page 3



- What would each student on the previous page predict?

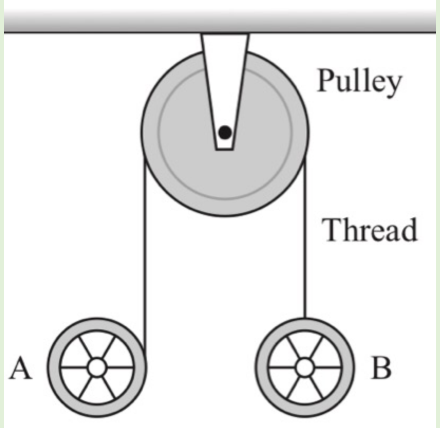
1. They have the same mass and same net force so the centers of mass have the same acceleration. The tensions have the same effect on translational motion.

   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.

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.

Dynamics of rigid bodies, page 3



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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**

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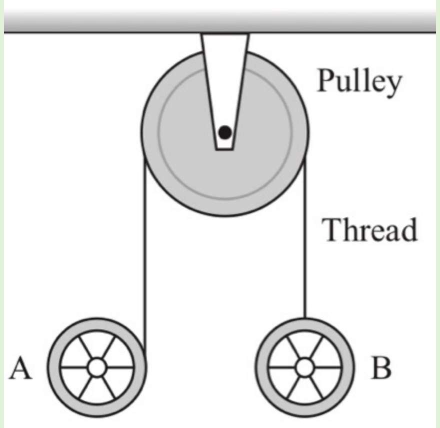
Dynamics of rigid bodies, page 3



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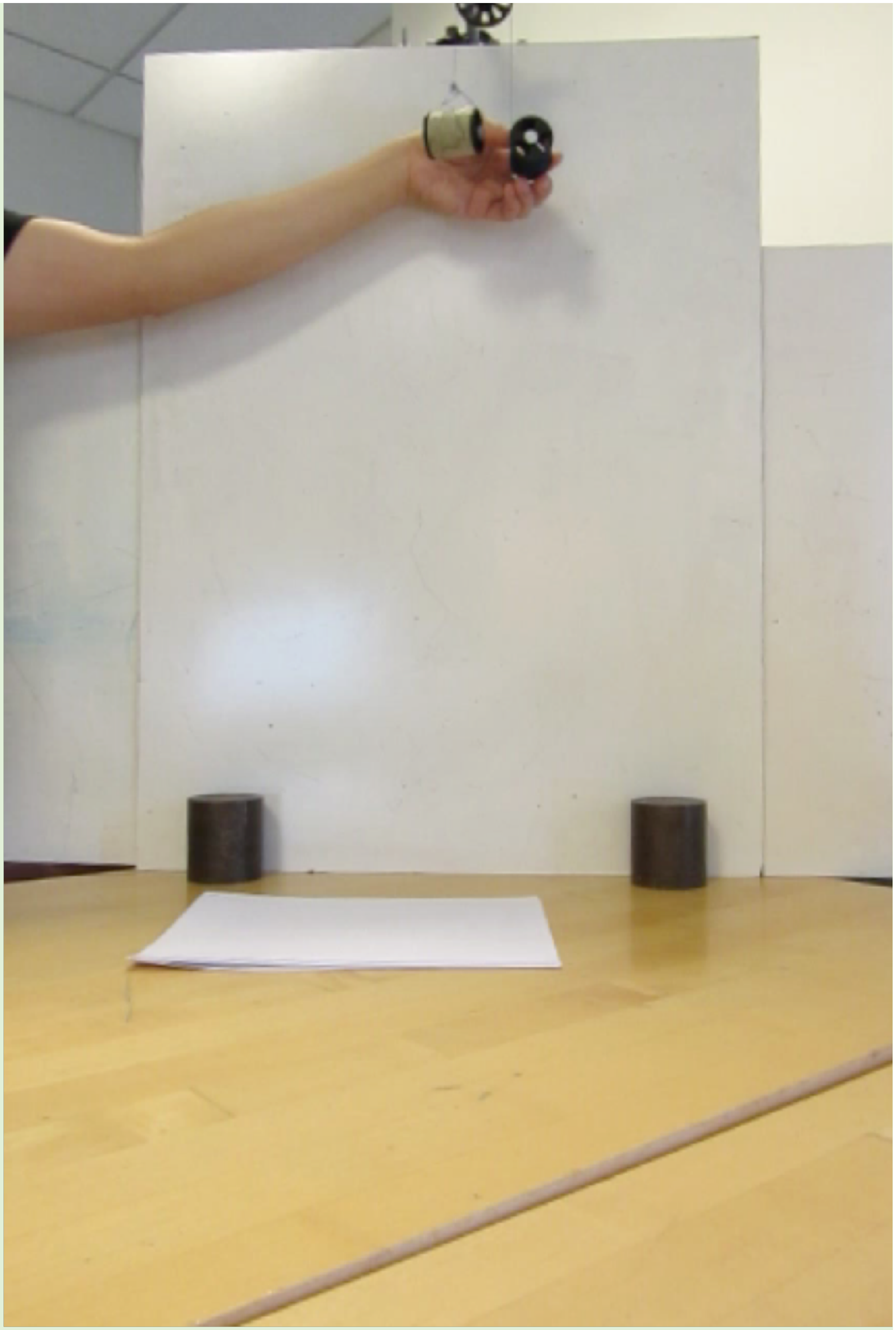
3. I was thinking about energy. They have the same total kinetic energy at the finish line. Since the spool has some rotational KE, it must have less translational KE.

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

Three different predictions

Spools connected by string



Small group activity: page 4

F. Suppose you want to decide how a given 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?

On page 4, students generalize what they have done in the tutorial.

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

Assessments of student learning

- **Pretests**: Typically after all lecture & textbook instruction but **before tutorial**.
  - Provide motivation for tutorial and yield insights into student reasoning
  - Many versions used to test aspects of student understanding

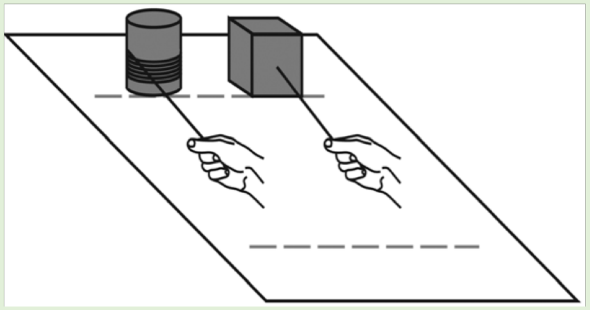
- **Post-tests:** After all instruction including *Tutorial* and *Tutorial Homework.*
  - A variety are used, of varying difficulty or in different context than pretests

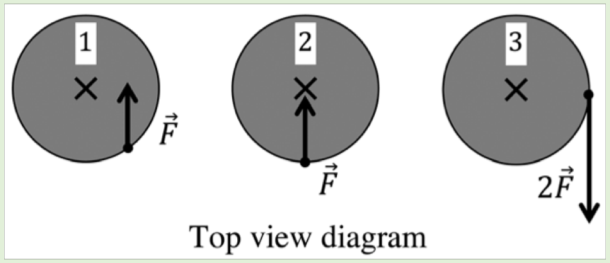
Note: Results are usually independent of instructor or textbook
with variations of *about* $\pm$ *5% from class to class.*

"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

Results from many Pretests & Post-tests

Sample questions:





	Results	
	Pretest	Post-tests (Various)
Correct (applying idea that net force is independent of point of application)	**5%**	**80%**
Common incorrect: Treating translation as reduced if force also results in rotation	80%	< 10%

Practical criterion
for effectiveness of a tutorial:

Post-test performance of introductory students

matches (or surpasses)

pretest performance of graduate students.

(Graduate TAs about 30% correct on the pretest for this topic.
Typically they are 100% on post-tests.)

Assessments of student learning at UW and beyond on many topics

Effect of tutorials on student performance

On qualitative problems:

- *much better*

(as illustrated in this workshop)

In addition:

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 in lecture and/or small group sections

In this workshop, we have tried to illustrate a generalization that is 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.

Tutorials are a way to engage students productively in thinking about important ideas (if led by well-prepared TAs).

Summary

This workshop has tried to illustrate the use of guiding questions in *Tutorials (and Physics by Inquiry).*

Results from research have demonstrated that sequences of questions can help close the gap between where students start and where they should be at the end of the course:

- <u>Early questions</u> ***<u>elicit</u>*** common incorrect student ideas
- <u>Intermediate questions</u> lead students to recognize and ***<u>confront</u>*** conflicts between early responses and real world results or physics formalism
- <u>Later questions</u> help students ***<u>resolve</u>*** conflicts

Study of physics should help students (and K-12 teachers) develop ability in:

- **Scientific thinking**
  - understanding nature of science (method, models, explanations)
- **Critical thinking**
  - distinguishing scientific reasoning from personal belief or opinion
- **Reflective thinking**
  - learning to ask the types of questions necessary to recognize when one does or does not understand a concept or principle
  - learning to ask the types of questions necessary to come to an understanding

These goals transcend the study of physics.