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
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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.
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 \textit{functional understanding}?

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

If not,

\textbf{what can be done?}

\textbf{In particular, what is possible in a typical introductory physics course with usual constraints?}
Tutorial components

• **Pretests** (~15 minutes)
  • *Usually given after* 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

- **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 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.”

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

The spool will translate and not rotate

• “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
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.*
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.*
• Draw for each spool:
  • an extended free-body diagram
  • a (point) free-body diagram
• Draw for each spool:
  • an extended free-body diagram
  • a (point) free-body diagram
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 \(\rightarrow\) **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.
• What would each student on the previous page predict?

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   Same forces, same mass $\rightarrow$ A lands at same time as B

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   T has less effect on A so A has larger net force down $\rightarrow$ A lands before B

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Dynamics of rigid bodies, page 3

• What would each student on the previous page predict?

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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 $\rightarrow$ **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 $\rightarrow$ **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 ± 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:

<table>
<thead>
<tr>
<th>Correct (applying idea that net force is independent of point of application)</th>
<th>Pretest</th>
<th>Post-tests (Various)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5%</td>
<td>80%</td>
<td></td>
</tr>
</tbody>
</table>

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:*            (as illustrated in this workshop)
  • much better

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:

• Early questions *elicit* common incorrect student ideas

• Intermediate questions lead students to recognize and *confront* conflicts between early responses and real world results or physics formalism

• Later questions help students *resolve* 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.*