Title: Improving physics instruction from kindergarten through graduate school: The role of research

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Abstract: <kw> overview of physics education, curriculum development, research, improve instruction, theory versus experiment, investigation, constructing concepts </kw>

Improving student learning: Lessons from physics education research

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Outline

- Overview of physics education research (PER)
- Research program of the physics education group at the University of Washington
  - Approach to research and curriculum development
  - Example with some generalizations

What is physics education research?

- An attempt to understand how students learn physics
  - Because it's there
  - Because it provides an objective and efficient way to improve instruction

- Approach is strongly influenced by the methodology of physics research

Physics education research

Produces:

- Evidence of student difficulties with physics topics
- Generalizations about how students learn
- Generalizations about effective instructional strategies
- Assessment tools to help improve instruction *(e.g., FCI, FMCE)*
- Instructional materials that help improve student learning (e.g., *Workshop Physics* by Laws, *Real-time Physics* by Thornton & Sokoloff)

Current research priorities

Empirical investigations

- Student learning of specific topics (introductory and upper division)
- Student ability to develop transferable reasoning skills
- The impact of beliefs about learning on learning itself
- General principles of effective instruction

Theoretical model-building

- Developing explanatory models for how people learn physics

"The Future of PER," Heron and Meltzer (*Am. J. Phys.* 2005)

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About UW

- Large public research university
  - 40,000 undergraduates
  - 12,000 graduate and professional students

- Physics department
  - ~2000 students enrolled in introductory courses (mostly engineering and biology majors)
  - 60 physics majors each year (largest program in U.S.)
  - 45 faculty
  - Major strengths: experimental neutrino physics (e.g., SNO), theoretical nuclear and particle physics, physics education, atomic physics, experimental gravitation

Physics Education Group
2005-2006

Faculty

Lillian C. McDermott

Paula Heron

Peter Shaffer

Lecturers & visiting faculty

Donna Messina*

David Meltzer

Paul van Kampen ('04-'05)

Postdoctoral researchers

Homeyra Sadaghiani

MacKenzie Stetzer

Physics PhD students

Hunter Close* (PhD 2005)

Matt Cochran (PhD 2005)

Andrew Crouse*

Mila Kryjevskaia

Beth Lindsey*

Research Coordinator

Karen Wosilait*

Support Staff

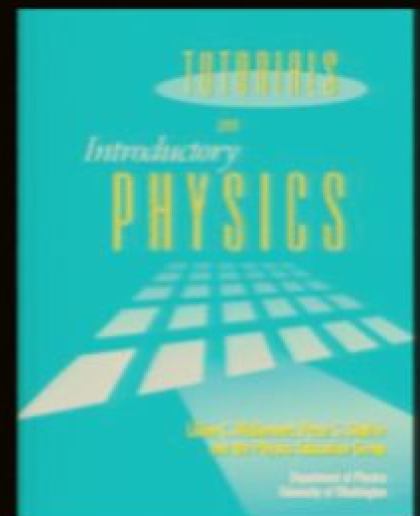
Nina Tosti

*former high school teachers

Physics Education Group
Curriculum Development Projects

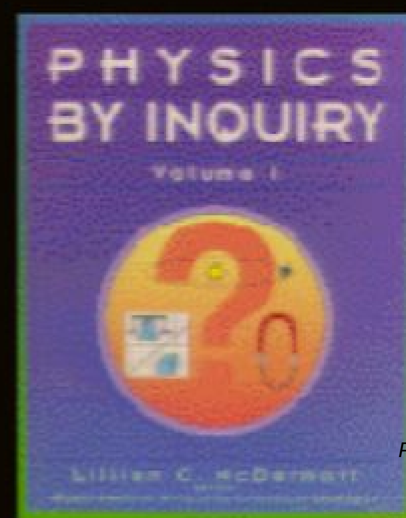
Improving student learning in introductory physics

Tutorials in Introductory Physics
Prentice Hall, First Edition, 2002
(Preliminary Edition, 1998)



Preparing K-12 teachers to teach physics and physical science

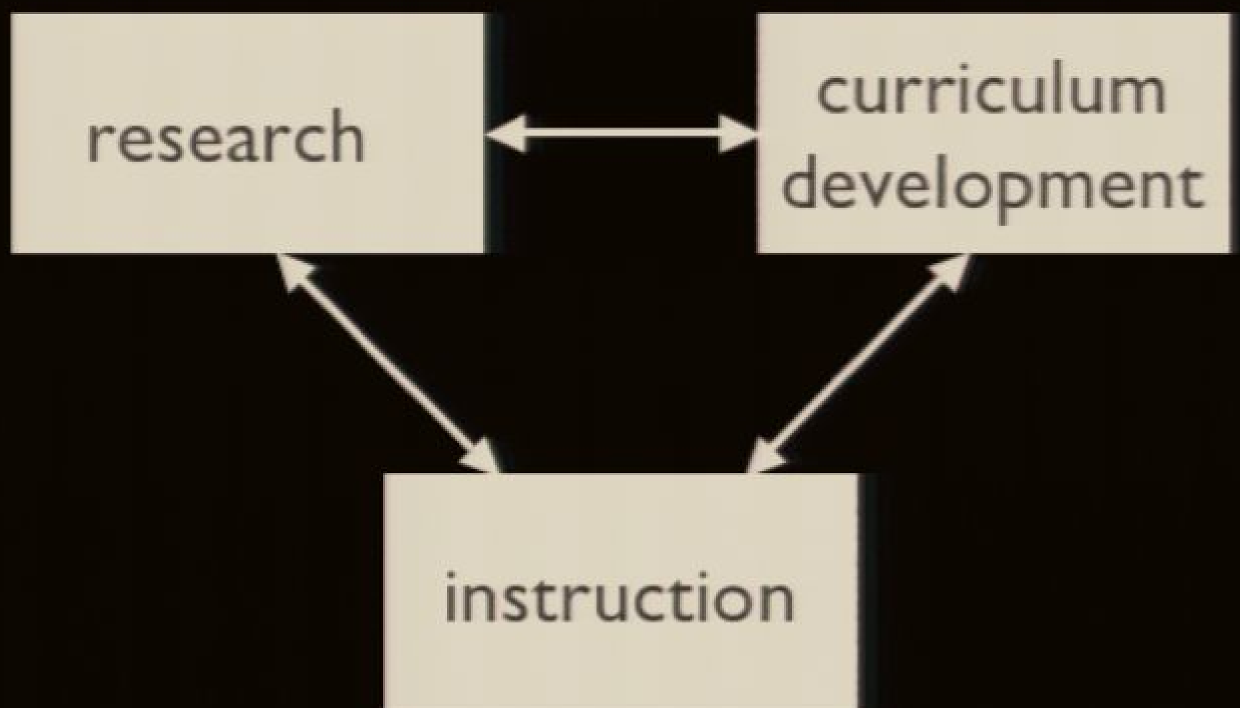
Physics by Inquiry
John Wiley & Sons, Inc., 1996



Topics covered

- *Tutorials in Introductory Physics*
  - Mechanics, E&M, waves, optics, fluids, basic thermal physics, basic modern physics
- *Tutorials in Physics* (2nd & 3rd year courses)
  - Quantum mechanics*, special and general relativity*, thermal and statistical physics*
- *Physics by Inquiry* (courses for K-12 teachers)
  - Properties of matter, Heat and temperature, Electric circuits, Astronomy by sight, Kinematics, Dynamics*, Relativity*, Simple machines*, Waves*, Physical optics*

*to be published


research
curriculum development
instruction

Example in the context of balancing

(with some generalizations)

Ortiz, Shaffer, and Heron (Am. J. Phys. 2005)

Context for investigation

At UW:

- Introductory calculus-based physics (physics & engineering majors)
- Sophomore engineering statics (civil & mechanical engineers)
- Teaching seminar for physics PhD students
- Special courses for prospective and practicing K-5 teachers

Other universities (Purdue, Colorado, Maryland, …)

- Introductory calculus-based and algebra-based physics courses

Step 1: Finding out what students are learning

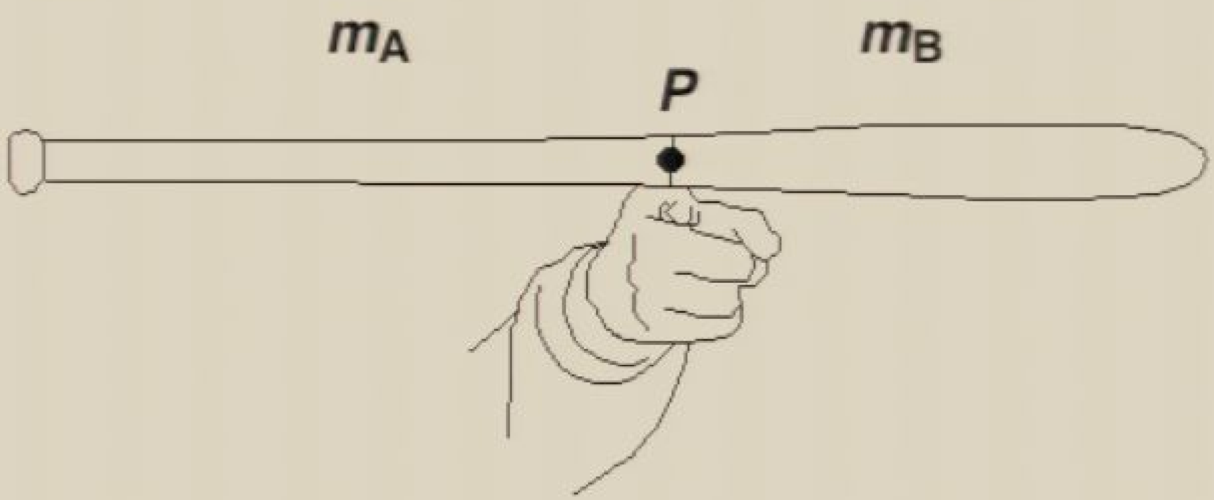
Step 2: Using results to guide the design of instruction

Step 3: Assessing the impact of instruction

Tasks that probe student understanding

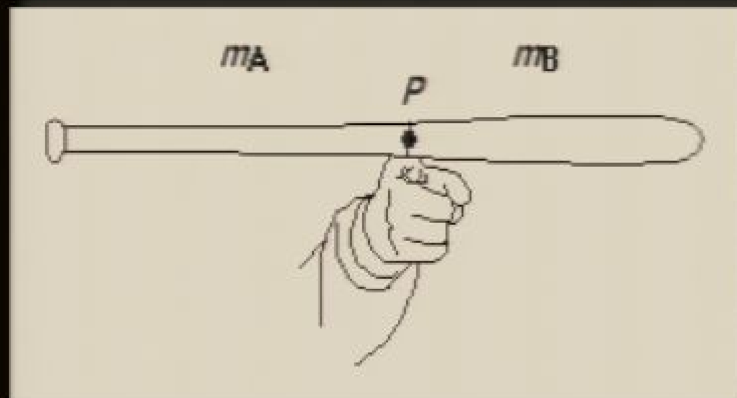
- Require a written or verbal explanation
- Cannot be answered by memorization and/or formula manipulation
- Are challenging (but not so difficult that responses are meaningless)
- Often require a prediction that can (in principle) be checked experimentally

Written question



A student balances a baseball bat on a finger. Compare the mass to the left and right of the balance point. Explain your reasoning.

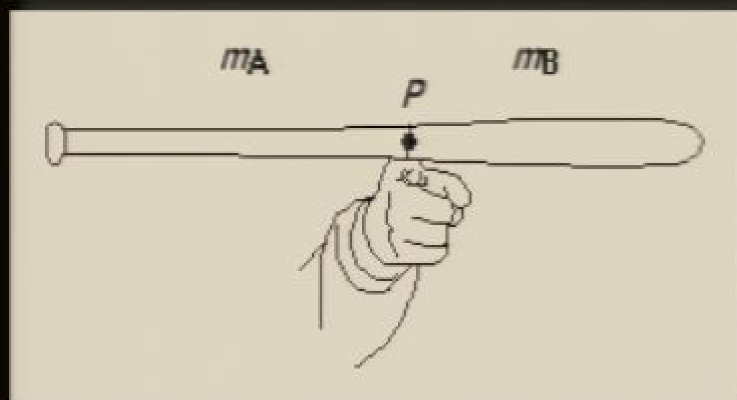
Sample student responses



Correct:

"Mass and distance are both factors whose product must be equal on both sides, thus m_A is less."

Sample student responses



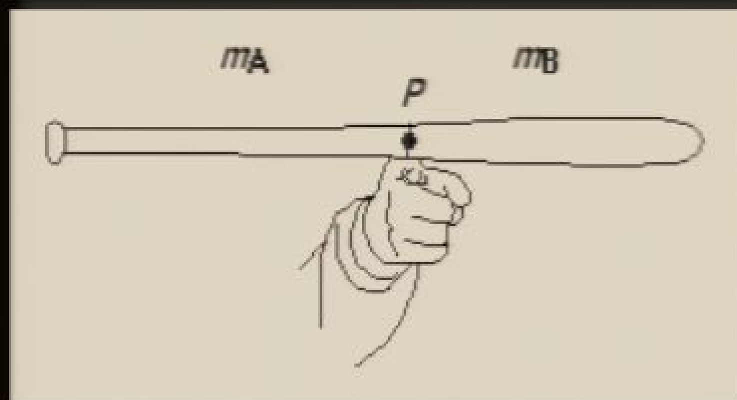
Correct:

"Mass and distance are both factors whose product must be equal on both sides, thus m_A is less."

Incorrect:

"If the bat is to be balanced, there must be an equal amount of mass to the left and right of point P."

Results from K-5 teachers



Correct response given by:

- 15% of practicing teachers in a one-week workshop ($N > 50$)

Factors not affecting results

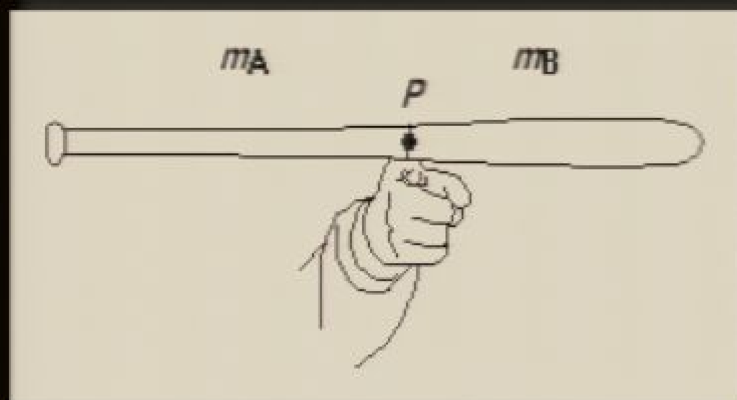
– Having previously taught a kit-based unit on balancing*

– Having helped prepare *other* teachers to teach a kit-based unit on balancing

*e.g., *Balance & Motion* (FOSS) or *Balancing and Weighing* (STC)

- Conceptual development does not necessarily occur as a result of teaching a topic.

Results from undergraduates



Correct response given by:

- 15% of science & engineering majors in introductory physics ($N > 1000$)
- 15% of engineering majors in statics ($N > 70$)

Factors not affecting results

- Traditional lecture instruction
- Traditional laboratory instruction

Evidence from research indicates that, on certain types of qualitative questions, student performance is essentially the same:

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

McDermott (Am J Phys, 1990)

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

Students must be intellectually active to develop a functional understanding.

Additional factors not affecting results

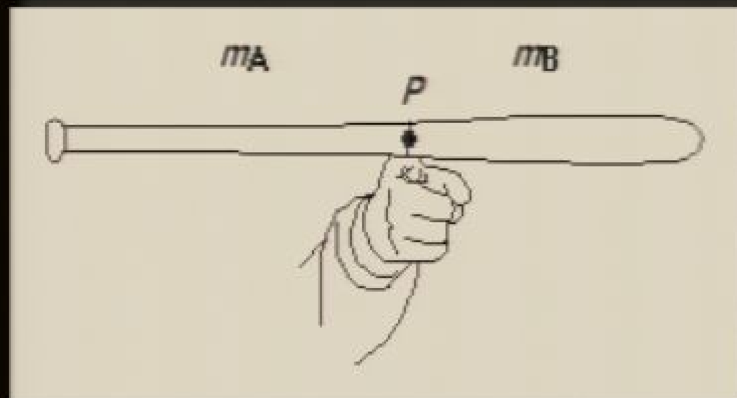
- "Hands-on" activities
- Collaborative group work

not guided by research

◊ Certain conceptual and reasoning difficulties are not addressed by traditional instruction.

◊ Even instruction that follows “best practices” may not address serious and persistent difficulties.

Results from physics PhD students



Correct response given by:

- 70% of graduate teaching assistants (N ~ 50)

- Study at a more advanced level often does not lead to increased understanding of basic material.

Step 1: Finding out what students are learning

→ Step 2: Using results to guide the design of instruction

Step 3: Assessing the impact of instruction

Research-based instructional materials

Take into account:

- Specific difficulties with the topic
- General instructional principles supported by research
  - Teaching by questioning
  - Promoting interaction among students
  - ...
- Practical considerations
  - Limited resources
  - Expectations of content "coverage" (e.g., pressure of standardized tests)
  - ...

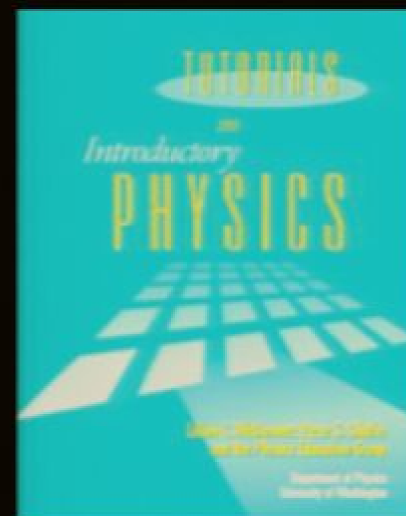
Are tested and revised on the basis of the intellectual impact on students

Tutorials in Introductory Physics

A mechanism for securing intellectual engagement in large lecture-based courses

Emphasis is on:

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



Emphasis is *not* on:

- solving standard (quantitative) textbook problems

Tutorial system at UW

- tutorial sessions
  - small groups (3-4) work through carefully structured worksheets
  - tutorial instructors (TAs) teach by questioning
- tutorial homework
- examination questions
  - all examinations include at least one question on topics from tutorials
- required weekly seminar for tutorial instructors
  - TA's, peer instructors, etc.

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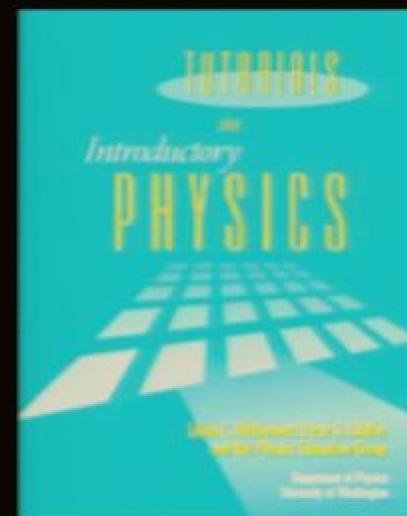

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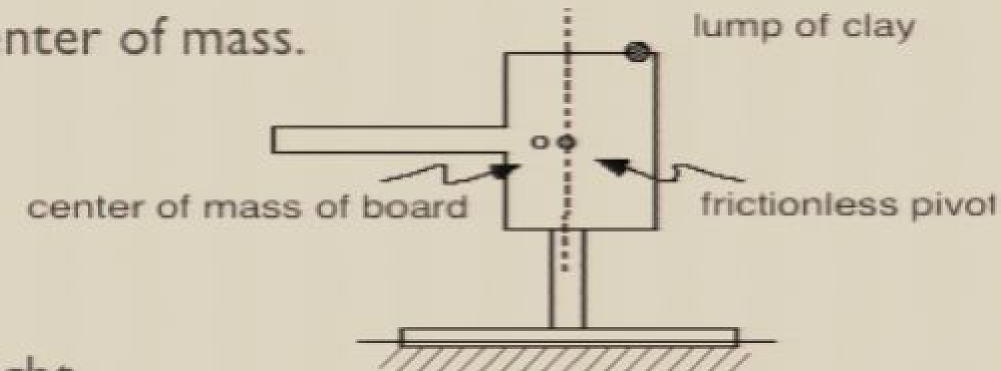
Example of tutorial activity

Hang board from hole to right of center of mass.



Use clay to balance the board.

Predict how the total mass to the right of the pivot compares to the total mass to the left.

a. Move the clay toward the pivot.

Does the board remain balanced?
Does the total mass to either side of the pivot change?

b. Balance board again, with larger piece of clay.

Does the total mass to either side of the pivot change?

Students recognize that both mass and its distribution influence balancing

Step 1: Finding out what students are learning

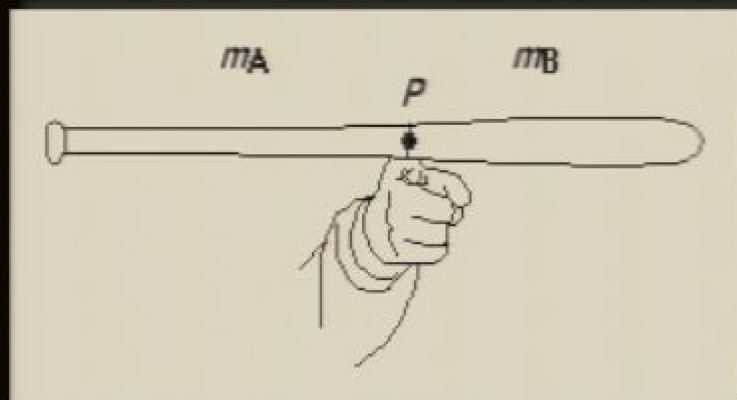
Step 2: Using results to guide the design of instruction

Step 3: Assessing the impact of instruction

Assessing student learning

- Compare performance on *similar* questions given pre- and post-tutorial in the same class
- Compare performance on *the same* question given after different instruction in different classes
  - e.g., with and without tutorial, or with different versions

Results after tutorial on static equilibrium



Correct response given by:

- 65% of students after a one-hour tutorial ($N \sim 65$)

  (compare to 15% correct without the tutorial)

- Research-based instruction can help students develop a functional understanding of important concepts.

Preparing teachers K-20

Discipline-specific skills and knowledge are needed for teaching effectively:

- Deep understanding of the subject matter
- Knowledge of the difficulties that students may face with the subject matter
- Experience with strategies proven to be effective

Need for special courses in physics departments for teachers K-20

- Prospective elementary/middle school teachers
  - Special courses in physical science (NOT descriptive, lecture-based "physics for poets")
- Prospective high school teachers
  - Special courses that revisit topics from introductory physics in depth
- Practicing teachers
  - Opportunities for ongoing professional development
- Current and future college and university faculty
  - Preparation that emphasizes content and instructional approach

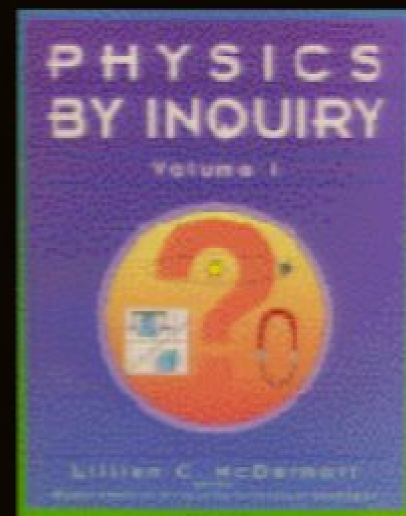
Professional development programs of UW PEG

- Elementary, middle, and high school teachers
  - Special physics courses for prospective teachers
  - National Summer Institutes and associated Continuation Course for practicing teachers
  - Short courses for K-8 teachers in local districts
- Graduate teaching assistants
  - Weekly seminar for PhD students in UW Physics Dept.
  - Internships in Summer Institute and/or Introductory Physics
- Faculty
  - Workshops at national meetings and other universities

Physics by Inquiry

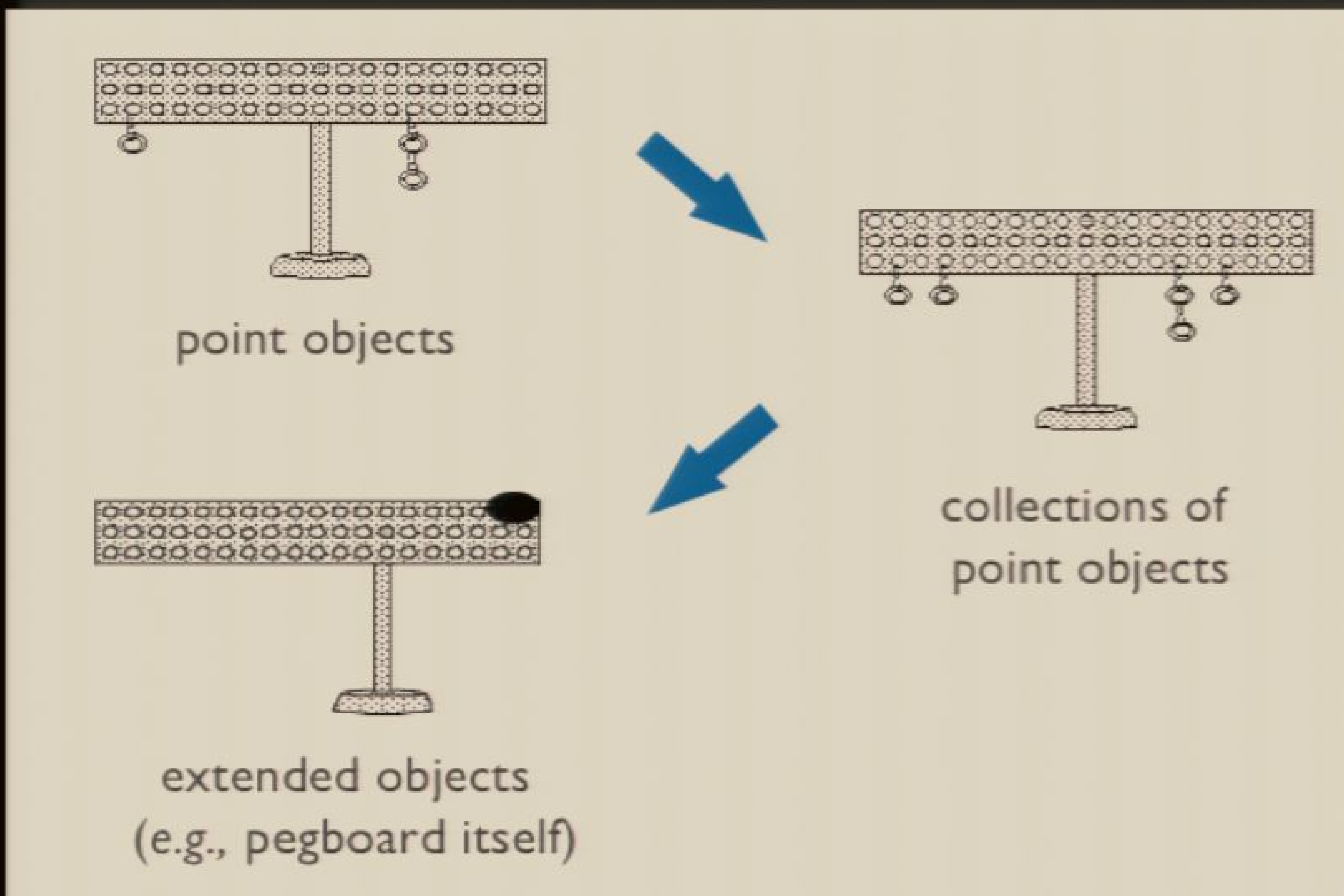
A self-contained laboratory-based curriculum to prepare K-12 teachers to teach science as a process of inquiry

- Designed for use in courses:
  - that are laboratory based, with no lectures.
  - where teaching is by questioning, not by telling.
- Content and process are taught together.
- Pedagogy is taught by example.
- Common student difficulties are explicitly addressed.



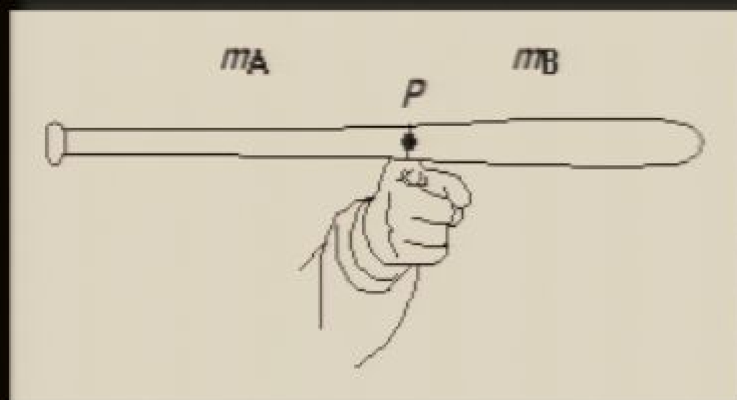
Approach is "guided inquiry"

Instructional sequence on balancing (> 30 hours)



Control of variables, algebraic representations, proportional reasoning emphasized

Results after PbI module on balancing



Correct response (on this and other questions) given by:

- *All* of the K-5 teachers

(compare to 65% of undergraduate science and engineering majors)

◊ Physics education research provides a rich resource for helping teachers at all levels improve their effectiveness