Research-based Active Learning in Physics as a Model for Progress in STEM Education

David E. Meltzer
Arizona State University
USA

Supported in part by U.S. National Science Foundation Grants #1256333 and #0817282

Outline

- Modern origins of active-learning instruction in STEM
- Evolution of research on student learning in physics
- Development of research-based active-learning instruction in STEM disciplines

The first public secondary school in the United States was established in Boston in 1821. From the very beginning, physics ["natural philosophy"] was included in the curriculum.

Boston (City of) 1820 Pub. school dept

PROCEEDINGS

OF THE

SCHOOL COMMITTEE,

OF THE

TOWN OF BOSTON,

RESPECTING AN

English Classical School.

IN SCHOOL COMMITTEE, JUNE 17, 1820.

Voted: That such of the resolutions offered by S. A. Wells, as relate to the establishment of an English Classical School in the townof Boston, be referred to a Sub-Committee of five, and the following gentlemen were chosen.

Mr. Samuel A. Wells,
Rev. John Pierpont,
Rev. Nathl. L. Frothingham.
Lemuel Shaw, &
Benjamin Russell, Esqrs.

At a meeting of the School Committee on the 26th October, the above Committee made a Report which was read: it was then

Voted: That it is expedient to establish an English Classical School, upon the plan stated in the report, in the town of Boston, and that the further consideration

[Boston 1820]

Surveying;
Mensuration of superficies and solids;
Forensic discussions.

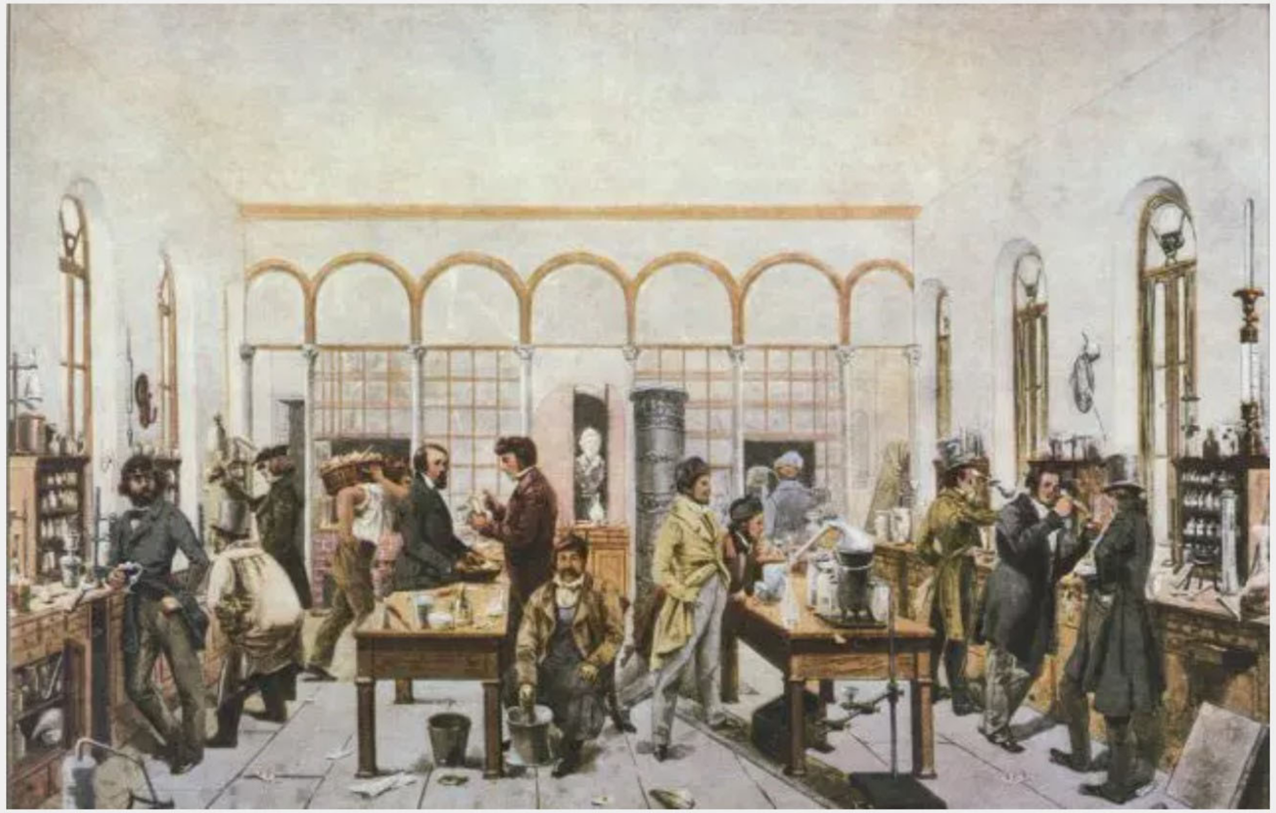
The studies of the 3d class—

Composition;
Exercises in criticism;
Declamation;
Mathematics;
Logic;
History, particularly that of the United States;
Natural Philosophy including Astronomy;
Moral and Political Philosophy.

} Continued

To conduct a seminary of this description, the Committee are of opinion, that one principal master, one submaster, and two ushers will be required;

1825



Liebig erhält die Position „ordentlicher Professor“ an der Universität Gießen. Seine Schwerpunkte sind folgende: Experimenteller Unterricht Er nutzt sein Labor als Werk- und Lehrstätte gleichzeitig und wird damit zum Vorbild für alle Zweige der naturwissenschaftlichen Experimentalforschung.

At around the same time, Justus von Liebig in Giessen became the first to use laboratory activities as a method for teaching chemistry. His method rapidly spread throughout Germany, and strongly influenced visiting American scientists.

Justus Liebigs chemisches Laboratorium auf dem Seltersberg zu Gießen um das Jahr 1840.

(Erbaut vom Universitäts-Baumeister Hofmann im Herbst 1839.)

The use of laboratories to *teach* the subject of chemistry was a ground-breaking innovation.

The Liebig laboratory in Giessen, today.

XXVI 34

Mays'sche Brochüren.

Geschichte des physikalischen Instituts der Universität Heidelberg.

Akademische Rede

zur Feier des Geburtsfestes des höchstseligen Grossherzogs

KARL FRIEDRICH

am 21. November 1885

bei Vortrag des Jahresberichts und Verkündung der akademischen Preise

gehalten

von

Dr. Georg Quincke

ordentl. Professor der Physik

d. z. Prorektor der Grossh. Bad. Universität Heidelberg.

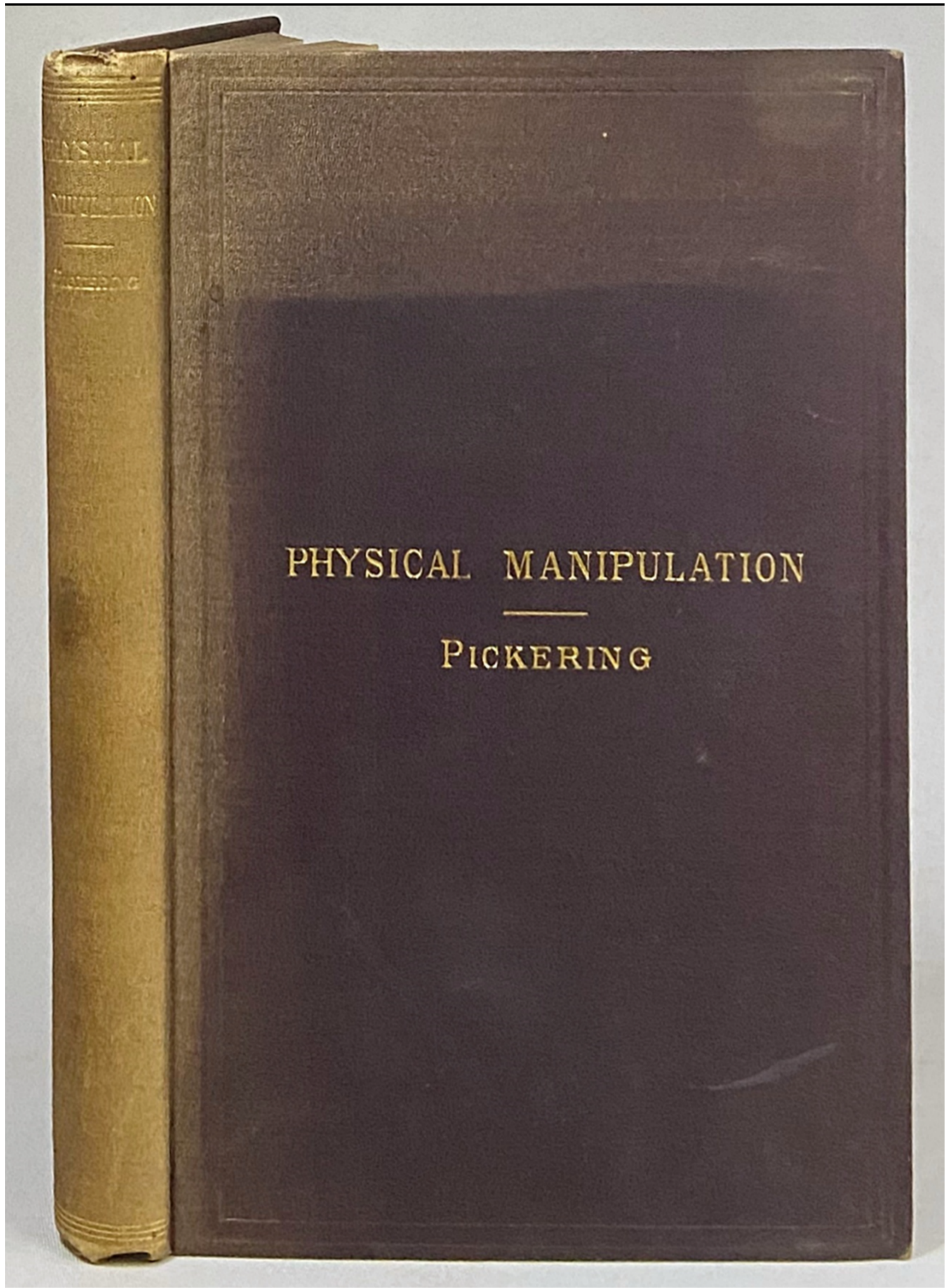
In Germany, laboratories for advanced university students in physics were established in Heidelberg by Philipp Jolly in 1846, and later similar laboratories were created at other German universities. However, they were not made an integral part of the curriculum for introductory, undergraduate students.

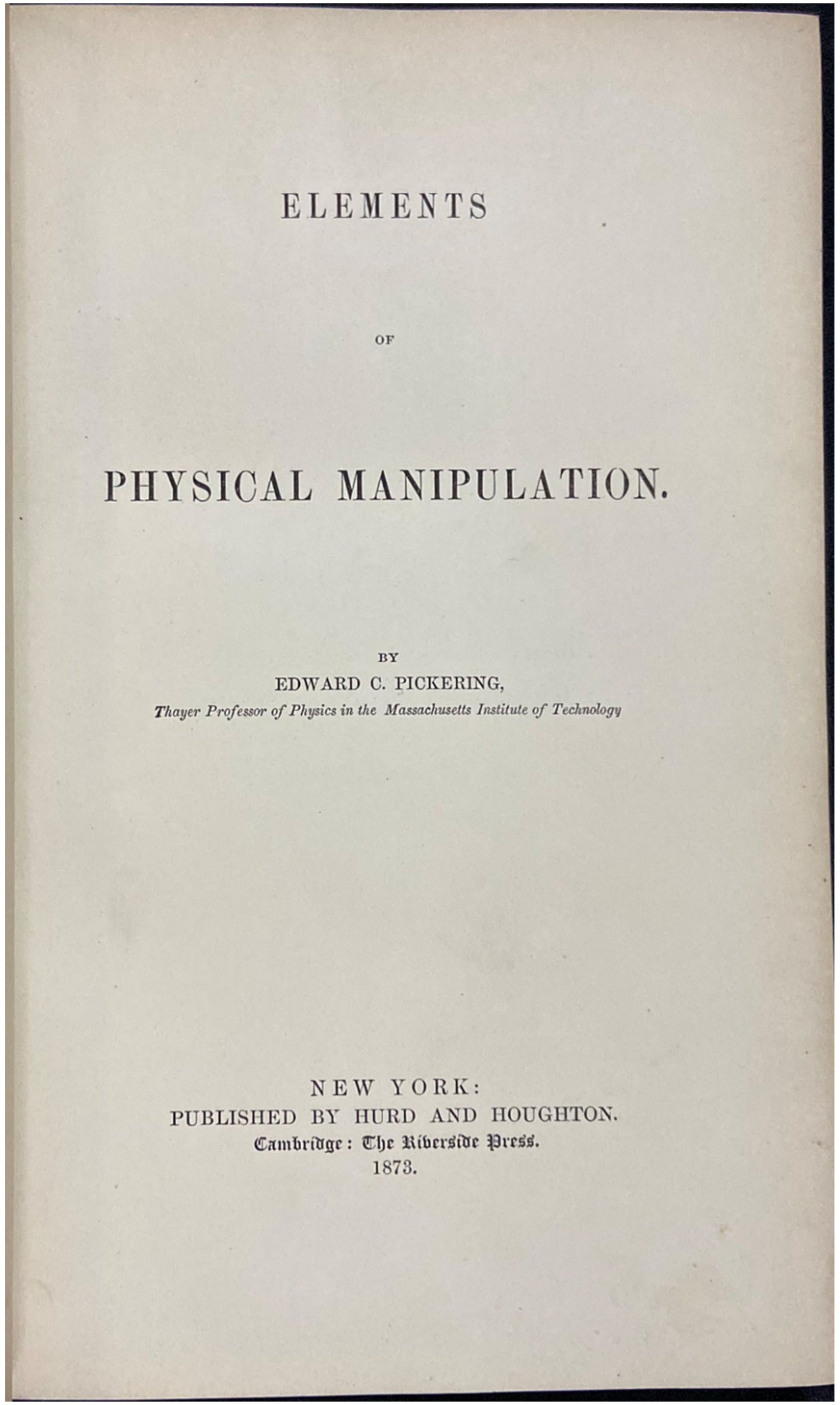
Ein physikalisches Laboratorium für Studirende richtete aber erst der Nachfolger von Muncke, Philipp Gustav Jolly ein, dem 1846 bei seiner Ernennung zum ordentlichen Professor der Physik zwei kleine Zimmer der Muncke'schen Wohnung hierfür überwiesen wurden.

European influence on the United States

Many American scientists visited and studied at European universities during the 1800s. They were particularly impressed by the high level of scientific education in Germany, especially by the widespread use of laboratory instruction.

They were determined to re-create similar facilities at U.S. universities, adapting the German model by making laboratory instruction available to a much larger population of students, including introductory undergraduate students.




ELEMENTS

OF

PHYSICAL MANIPULATION.

BY
EDWARD C. PICKERING,
Thayer Professor of Physics in the Massachusetts Institute of Technology

NEW YORK:
PUBLISHED BY HURD AND HOUGHTON.
Cambridge: The Riverside Press.
1873.

Edward Pickering's laboratory course at MIT for undergraduate physics students went into operation in 1869, perhaps the first of its type in the world.

His laboratory manual, "Elements of Physical Manipulation" (1873; 1876) had enormous influence on university physics instruction throughout the United States.

Pickering’s model spread throughout the United States, slowly at first, then much more rapidly. Wellesley College (here shown in 1895) was one of the first to adopt the new course.

THE

ELEMENTS OF PHYSICS,

DEMONSTRATED BY

THE STUDENT'S OWN EXPERIMENTS.

BY

GUSTAVUS HINRICHS, A. M.

Professor of Physical Science in the State University of Iowa; Member, or Correspondent. of Scientific Societies at Berlin, Vienna, Koenigsberg, Emden, etc. etc.

WITH A PLATE.

DAVENPORT, IOWA, U. S.
PUBLISHED BY GRIGGS, WATSON & DAY,
LEIPZIG: F. A. BROCKHAUS.
1870.

THE

SCHOOL LABORATORY

OF

PHYSICAL SCIENCE,

Edited by Prof. Gustavus Hinrichs.

Vol. II. 1872. *No.* 1

CONTENTS.

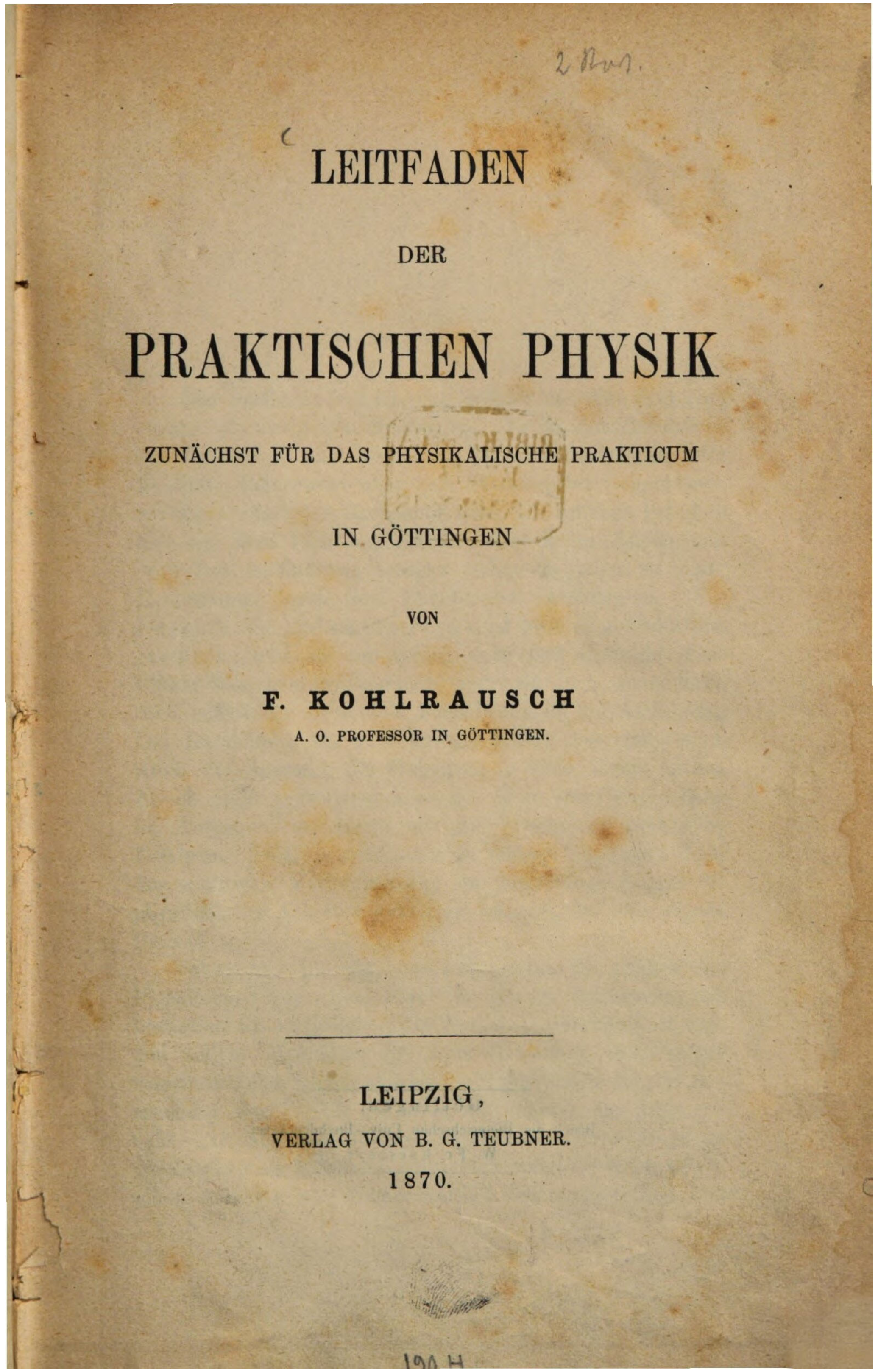
WITH ONE PLATE.

PUBLISHED QUARTERLY, BY THE EDITOR.

Terms: One Dollar per annum, in advance.

IOWA CITY, IOWA:
GRIGGS, WATSON, & DAY, PRINTERS, DAVENPORT.
1872.

Gustavus Hinrichs, an immigrant from Germany, established a similar undergraduate laboratory course in 1870 at the University of Iowa.



2 Bd.

LEITFADEN

DER

PRAKTISCHEN PHYSIK

ZUNÄCHST FÜR DAS PHYSIKALISCHE PRAKTICUM

IN GÖTTINGEN

VON

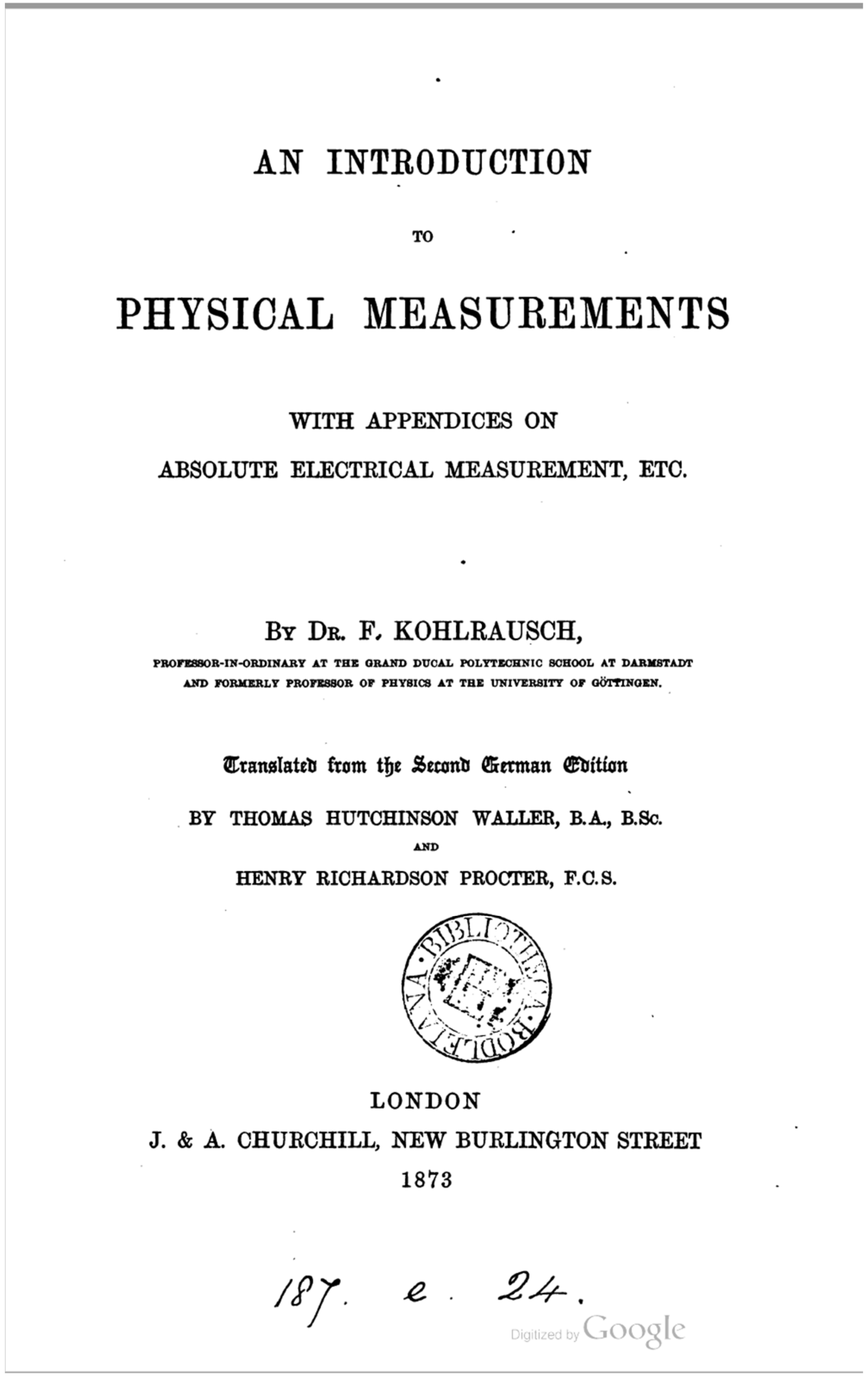
F. KOHLRAUSCH

A. O. PROFESSOR IN GÖTTINGEN.

LEIPZIG,

VERLAG VON B. G. TEUBNER.

1870.



AN INTRODUCTION

TO

PHYSICAL MEASUREMENTS

WITH APPENDICES ON

ABSOLUTE ELECTRICAL MEASUREMENT, ETC.

BY DR. F. KOHLRAUSCH,

PROFESSOR-IN-ORDINARY AT THE GRAND DUCAL POLYTECHNIC SCHOOL AT DARMSTADT AND FORMERLY PROFESSOR OF PHYSICS AT THE UNIVERSITY OF GÖTTINGEN.

Translated from the Second German Edition

BY THOMAS HUTCHINSON WALLER, B.A., B.Sc.

AND

HENRY RICHARDSON PROCTER, F.C.S.

LONDON

J. & A. CHURCHILL, NEW BURLINGTON STREET

1873

In Germany, Friedrich Kohlrausch's *Leitfaden der Praktischen Physik* (1870) became the standard laboratory manual for university physics courses.

It was translated into English and used in some U.S. universities as well.

Zeitschrift

für den

Physikalischen und Chemischen Unterricht.

X. Jahrgang. **Sechstes Heft.** November 1897.

Der Physikunterricht an den höheren Schulen der Vereinigten Staaten.

Von

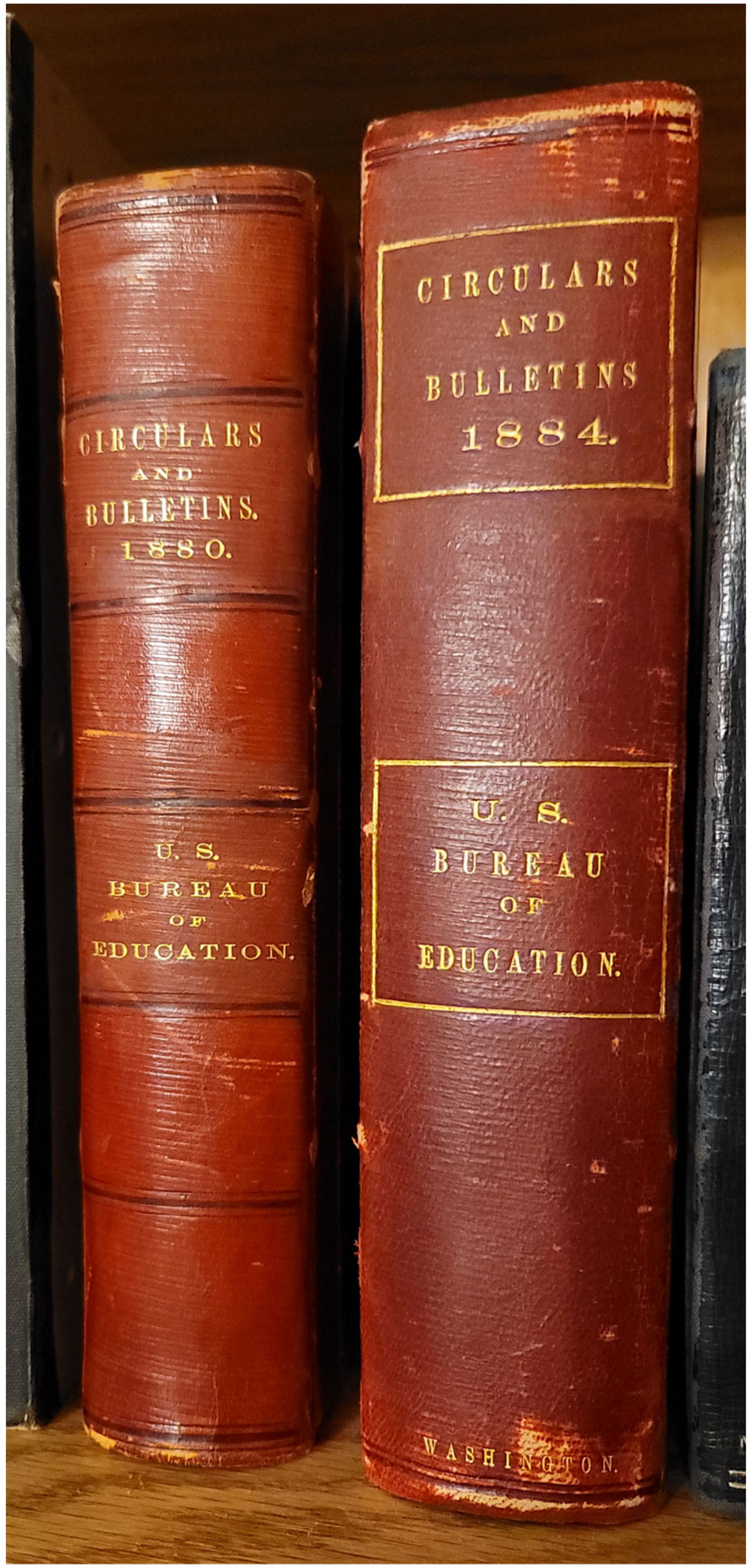
F. Poske.

1. In einem Aufsatze, der vor Jahresfrist in der New-Yorker *Educational Review* erschien, hat ein amerikanischer Schulmann, Dr. Edward J. Goodwin, ein ungünstiges Urteil über den naturwissenschaftlichen Unterricht auf preufsischen Schulen abgegeben, und demgegenüber das amerikanische Unterrichtsverfahren als Muster aufgestellt (vgl. den Bericht im laufenden Jahrgang dieser Zeitschrift *S. 161*). Es erwächst uns daraus die Verpflichtung, die Eigentümlichkeiten jenes Verfahrens genauer ins Auge zu fassen, und sofern es gerechtfertigt scheint, eine dementsprechende Umgestaltung unseres eignen Unterrichtsbetriebes anzustreben.

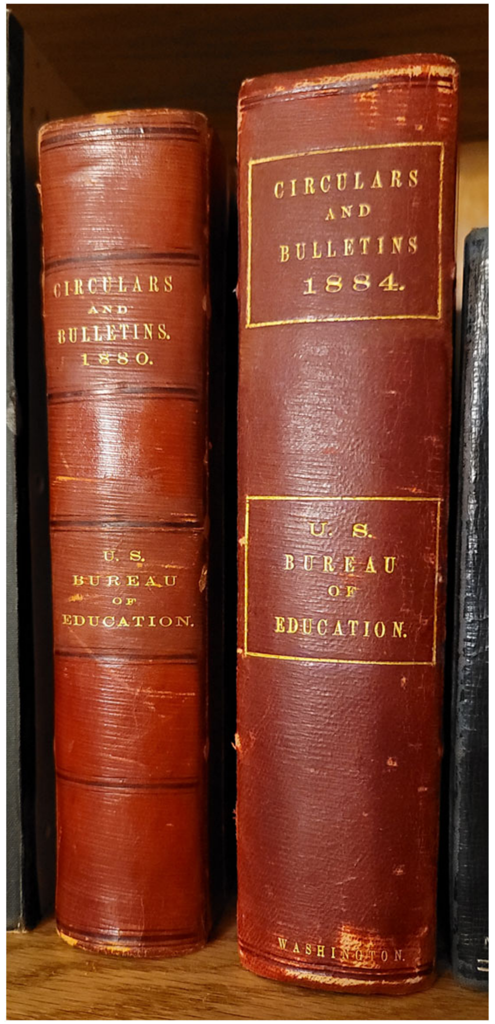
Eine unseren „Lehrplänen" vergleichbare Normierung hat der Unterricht an den höheren Schulen der Vereinigten Staaten durch die Beschlüsse des Zehnerausschusses erhalten, den die *National Educational Association* im Jahre 1892 eingesetzt hat. In neun Kommissionen, die von je zehn Mitgliedern aus Schul- und Universitätskreisen gebildet waren, wurden die verschiedenen Unterrichtsgegenstände erörtert und die Ergebnisse der Beratungen in dem *Report of the Comittee on secondary school studies* (*Washington 1893*) veröffentlicht. Dieser in vieler Hinsicht ausgezeichnete Bericht liefert auch den besten Anhalt für die Beurteilung der Unterrichtsverhältnisse, zumal

German and U.S. science educators visited each other's schools, read each other's writings, and exchanged ideas with each other. The mutual influence started early in the 1800s and continued strongly up until the first world war.

In 1880 and 1884, two major reports were published by the U.S. Bureau of Education regarding the teaching of physics and chemistry throughout the United States. Thousands of schools were surveyed, and hundreds of instructors were asked to submit comments. Similar educational work in other countries was examined in detail.



Nationwide surveys of science teaching in U.S. schools

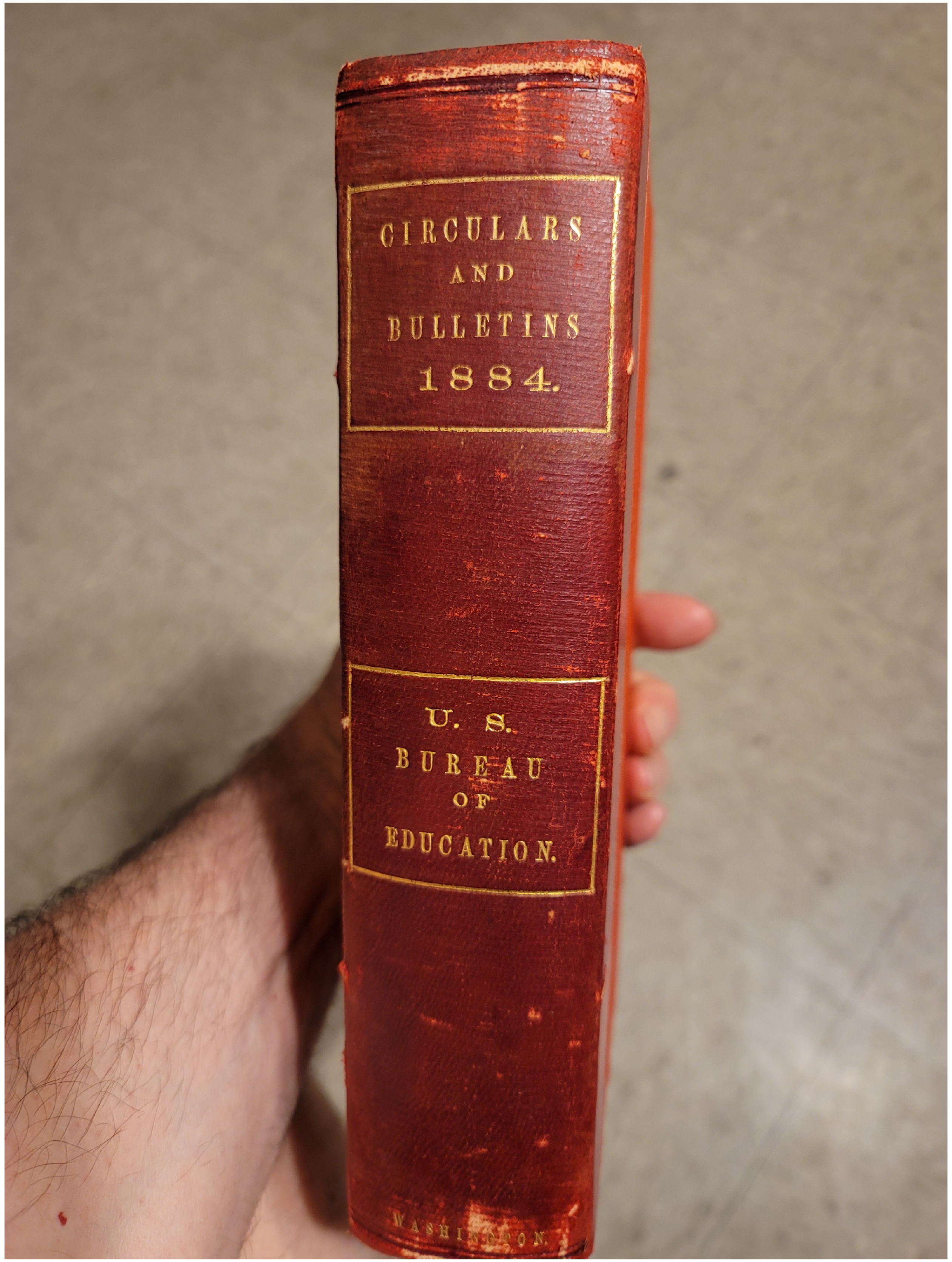


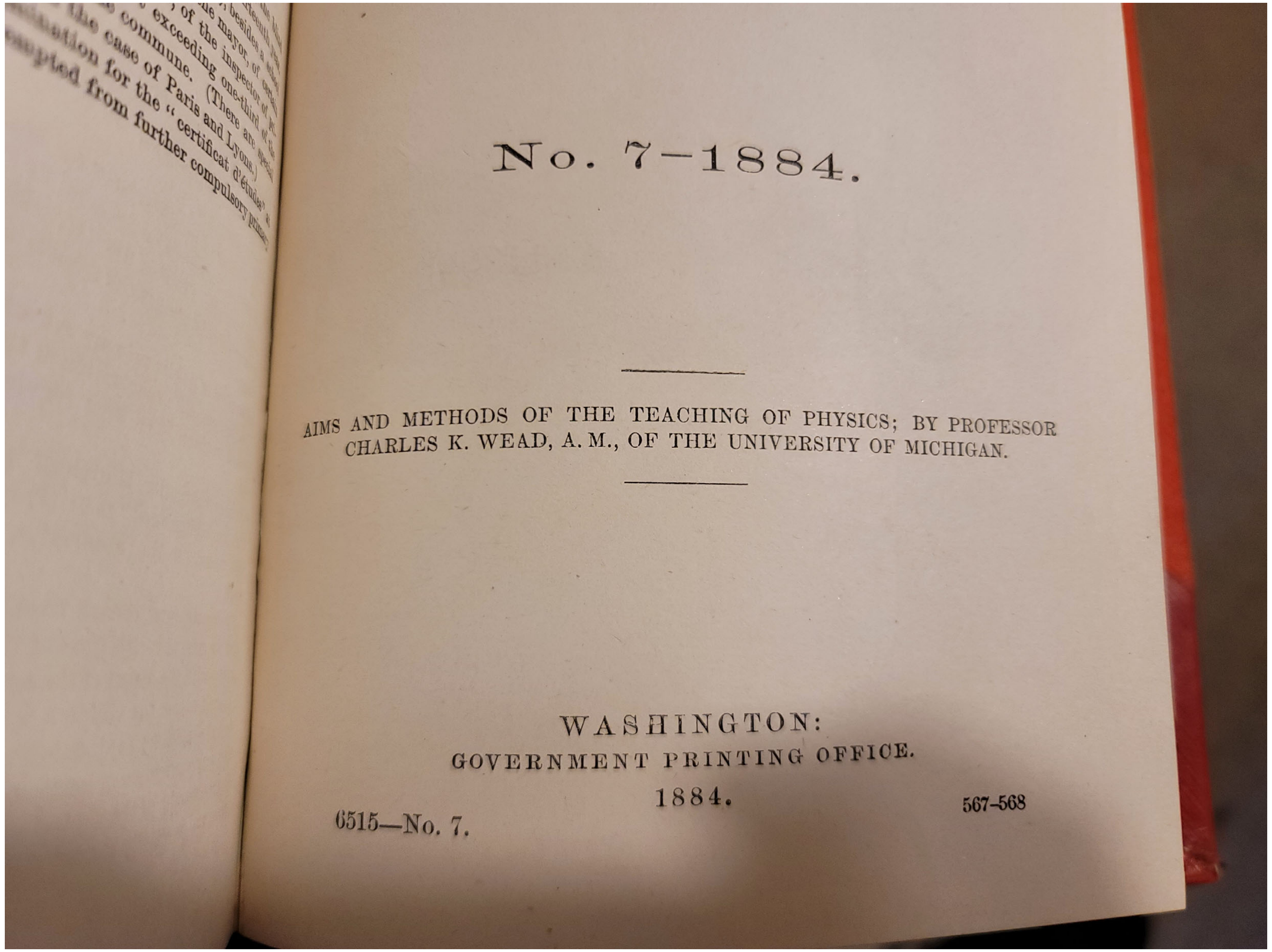
*F.W. Clarke, *A Report on the Teaching of Chemistry and Physics in the United States* (1880)

**C.K. Wead, Aims and Methods of the Teaching of Physics (1884)

Nationwide surveys of science teaching in U.S. schools

- Surveys of secondary-school and university teachers of chemistry and physics in 1880 and 1884 revealed:
  - Rapid expansion in use of laboratory instruction
  - Strong support of “inductive method” of instruction for secondary school in which experiment precedes explicit statement of principles and laws





No. 7—1884.

AIMS AND METHODS OF THE TEACHING OF PHYSICS; BY PROFESSOR CHARLES K. WEAD, A. M., OF THE UNIVERSITY OF MICHIGAN.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1884.

6515—No. 7. 567-568

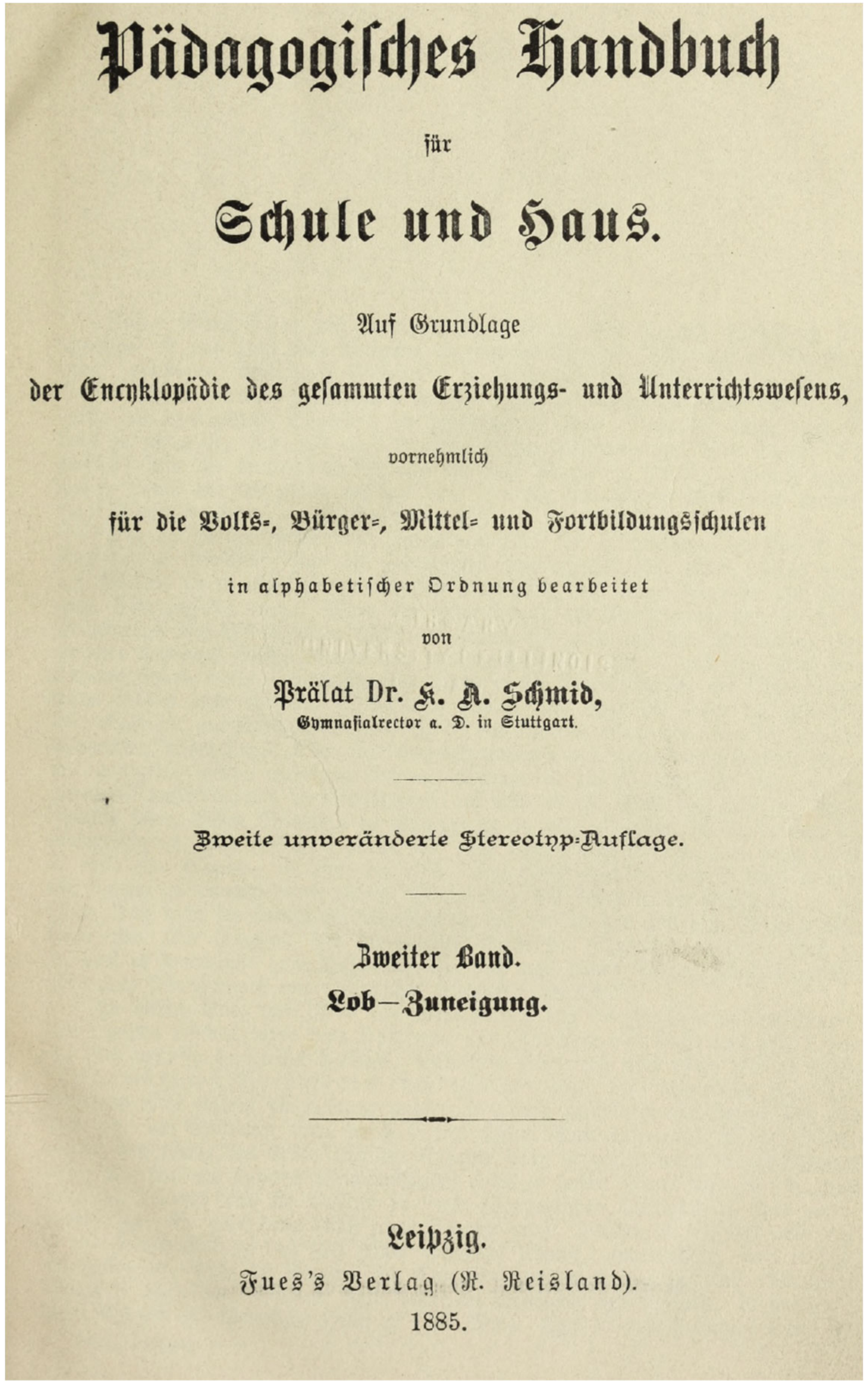
given to the simplest notions of the three states of matter, to the atmosphere, water, &c., with experiments. In the last two years natural history is reviewed and extended, and simple notions of physics are given, including facts under heat, light, and electricity. Simple illustrative collections are supplied by the state to the poorer schools.

GERMANY.

OFFICIAL PROGRAMS.

The Gymnasien, &c.—The plans of study in the Prussian higher schools have recently been thoroughly revised. From the circular of the minister of spiritual, educational, and medical affairs of March 31, 1882, and from a number of school reports, mostly from Berlin, the following facts and extracts are taken. It should be premised that students entering any of the four higher schools are at least nine years old, have had about three years' training in a Vorschule or elsewhere, and begin at once on Latin or French.

In the *Gymnasien* two hours a week are devoted to science from the Sexta through the nine years' course; in all, eighteen hours; formerly only fourteen hours. Physics (including chemistry) occupies the last four years. The time given to this branch is therefore equivalent to eight hours a week for one year; formerly it was but six hours. Compare Table II, page 158.



Pädagogisches Handbuch

für

Schule und Haus.

Auf Grundlage

der Encyklopädie des gesammten Erziehungs- und Unterrichtswesens,

vornehmlich

für die Volks-, Bürger-, Mittel- und Fortbildungsschulen

in alphabetischer Ordnung bearbeitet

von

Prälat Dr. K. A. Schmid,

Gymnasialrector a. D. in Stuttgart.

Zweite unveränderte Stereotyp-Auflage.

Zweiter Band.

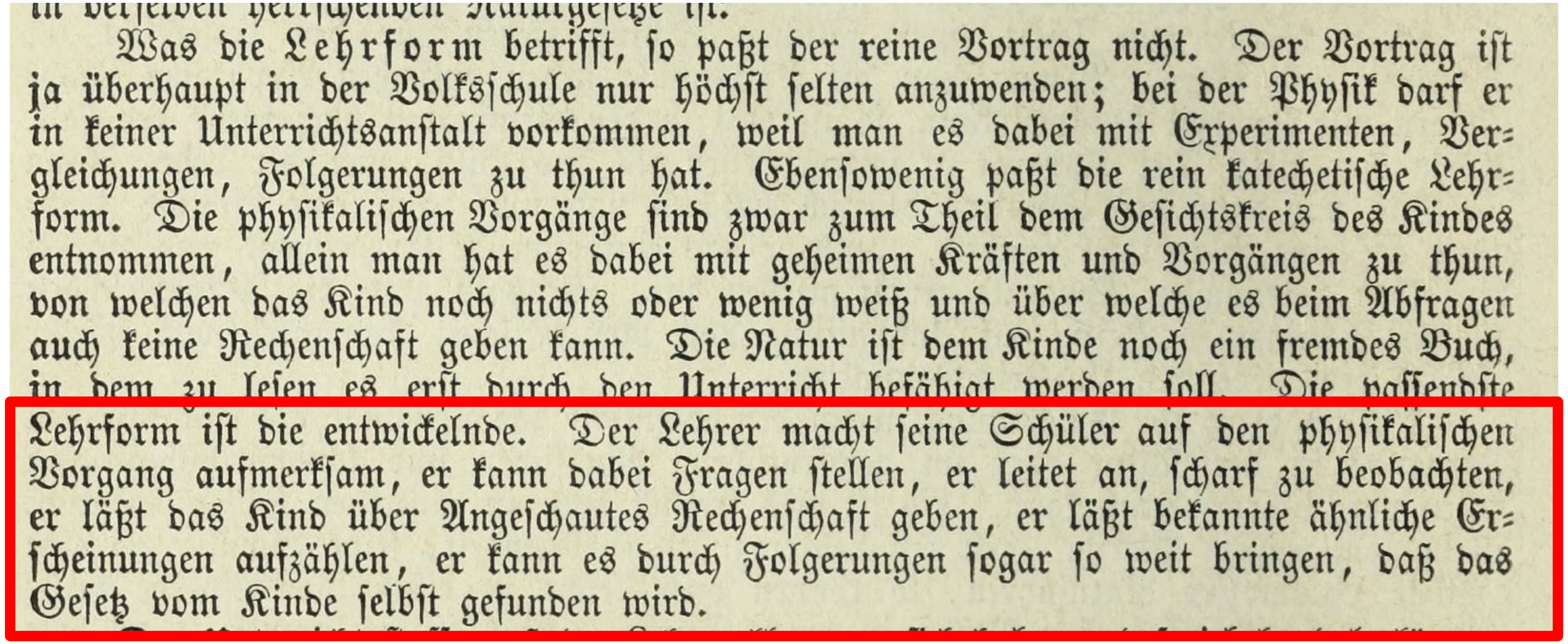
Lob—Zuneigung.

Leipzig.

Fues's Verlag (R. Reisland).

1885.

The 1884 report by Charles Wead included detailed descriptions of science instruction methods in other countries. Among the works he cited in detail was an article by Maier in Schmid's *Pädagogisches Handbuch*.



in derselben herrschenden Naturgesetze ist.

Was die Lehrform betrifft, so paßt der reine Vortrag nicht. Der Vortrag ist ja überhaupt in der Volksschule nur höchst selten anzuwenden; bei der Physik darf er in keiner Unterrichtsanstalt vorkommen, weil man es dabei mit Experimenten, Vergleichungen, Folgerungen zu thun hat. Ebensowenig paßt die rein katechetische Lehrform. Die physikalischen Vorgänge sind zwar zum Theil dem Gesichtskreis des Kindes entnommen, allein man hat es dabei mit geheimen Kräften und Vorgängen zu thun, von welchen das Kind noch nichts oder wenig weiß und über welche es beim Abfragen auch keine Rechenschaft geben kann. Die Natur ist dem Kinde noch ein fremdes Buch, in dem zu lesen es erst durch den Unterricht befähigt werden soll. Die passendste Lehrform ist die entwickelnde. Der Lehrer macht seine Schüler auf den physikalischen Vorgang aufmerksam, er kann dabei Fragen stellen, er leitet an, scharf zu beobachten, er läßt das Kind über Angeschautes Rechenschaft geben, er läßt bekannte ähnliche Erscheinungen aufzählen, er kann es durch Folgerungen sogar so weit bringen, daß das Gesetz vom Kinde selbst gefunden wird.

“Der Lehrer macht seine Schüler auf den physikalischen Vorgang aufmerksam, er kann dabei Fragen stellen, er leitet an, scharf zu beobachten, er läβt das Kind über Angeschautes Rechenschaft geben, er läβt bekannte ähnliche Erscheinungen aufzählen, er kann es durch Folgerungen sogar so weit bringen, daβ das Gesetz vom Kinde selbst gefunden wird.”

--Oberlehrer J. G. Maier, 1884

The "Inductive Method"

For younger students in Germany, and for older, secondary-school students in the United States, a popular form of physics instruction of the late 1800s was the "inductive method."

Students were guided to deduce general concepts and principles through analysis of their own experiments and observations.

In the United States in the present day, this general method has come to be called "inquiry-based active learning."

A TEXT-BOOK

ON THE

ELEMENTS OF PHYSICS

FOR

HIGH SCHOOLS AND ACADEMIES.

BY

ALFRED P. GAGE, A.M.,

INSTRUCTOR IN PHYSICS IN THE ENGLISH HIGH SCHOOL, BOSTON, MASS.

BOSTON:

PUBLISHED BY GINN, HEATH, & CO.

1882.

1882: First U.S. secondary-school physics textbook to employ the "inductive method"

First U.S. “Active-Learning” Physics Textbook (1882):

A. P. Gage, *A Textbook of the Elements of Physics for High Schools and Academies*

“The book which is the most conspicuous example now in the market of this inductive method is Gage's. Here, although the principles and laws are stated, the experiments have preceded them;

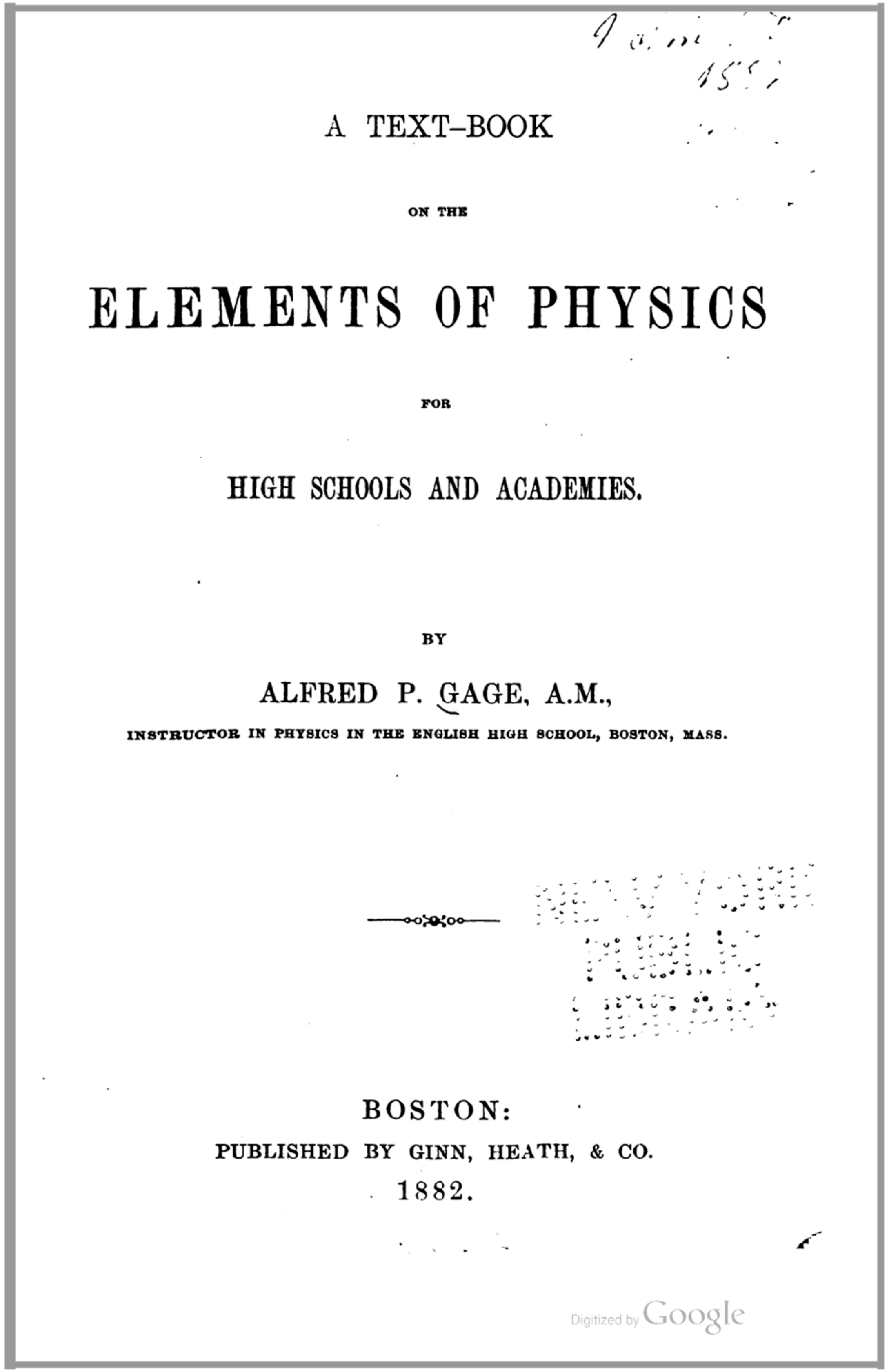
First U.S. "Active-Learning" Physics Textbook (1882):

A. P. Gage, *A Textbook of the Elements of Physics for High Schools and Academies*

"The book which is the most conspicuous example now in the market of this inductive method is Gage's. Here, although the principles and laws are stated, the experiments have preceded them; many questions are asked in connection with the experiments that tend to make the student active, not passive, and allow him to think for himself before the answer is given, if it is given at all."

C.K. Wead,

Aims and Methods of the Teaching of Physics (1884), p. 120.



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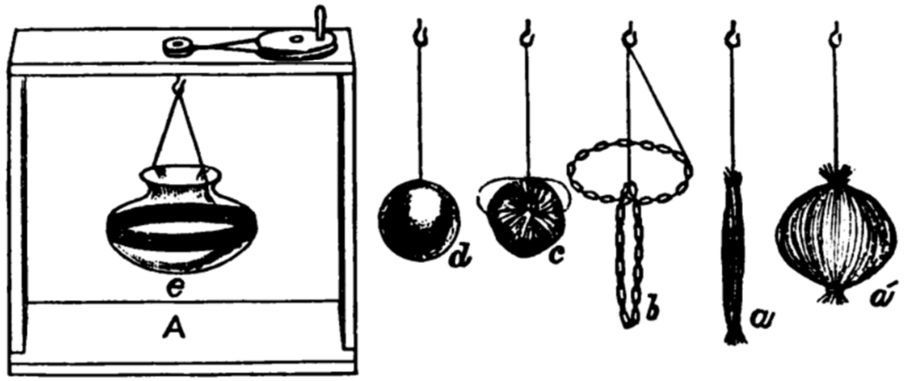
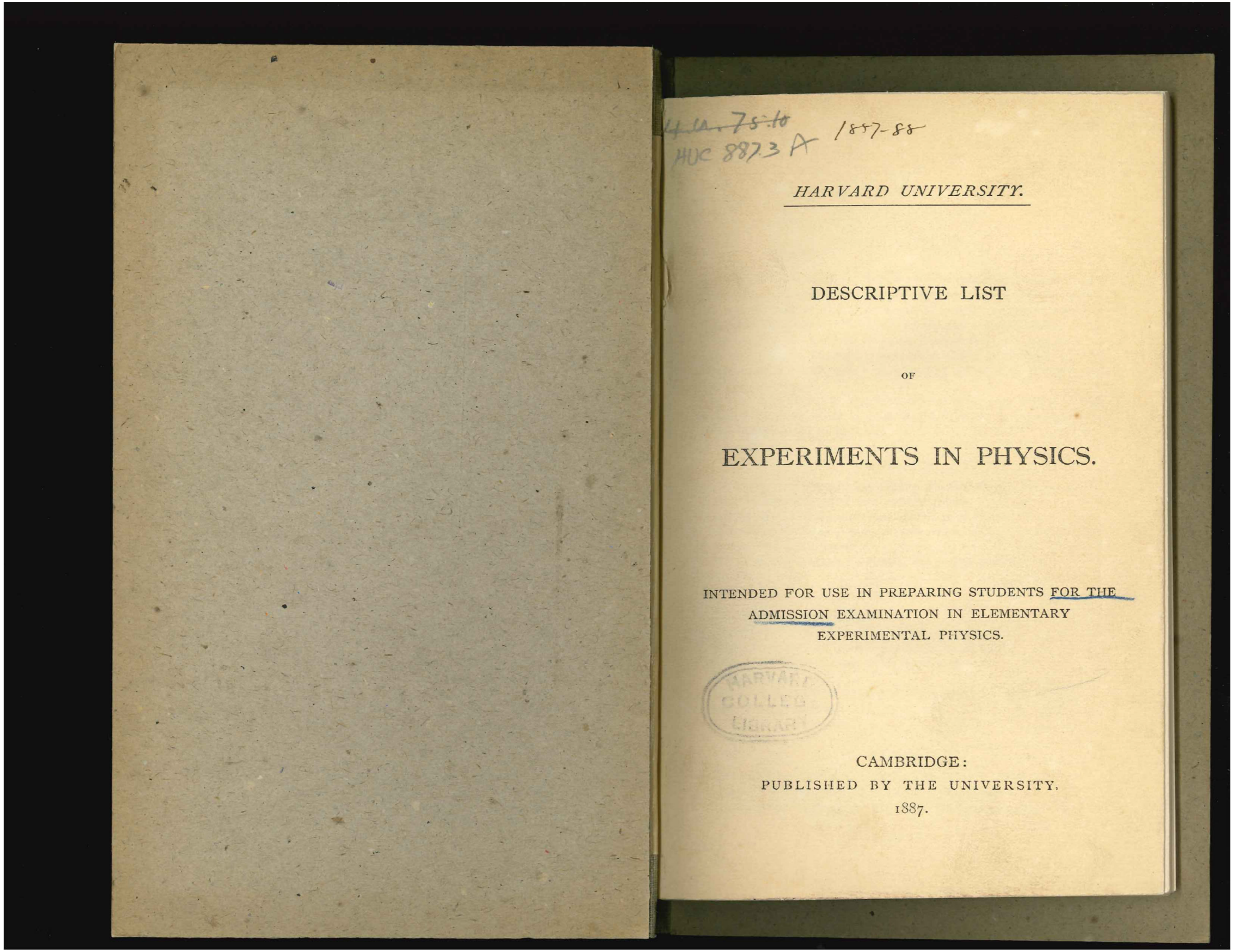
"Many questions are asked…" and students are often asked to explain their reasoning

Experiment. Arrange some kind of rotating apparatus, *e.g.*, A, Figure 84. Suspend a skein of thread *a* by a string, and rotate; it assumes the shape of the oblate spheroid *a′*. This illustrates the probable method by which the earth, on the supposition that it was once in a fluid state, assumed its present spheroidal state. (Explain.) Suspend a glass fish aquarium *e*, about one-tenth full of colored water, and rotate. The liquid gradually leaves the bottom, rises, and forms an

Fig. 85.

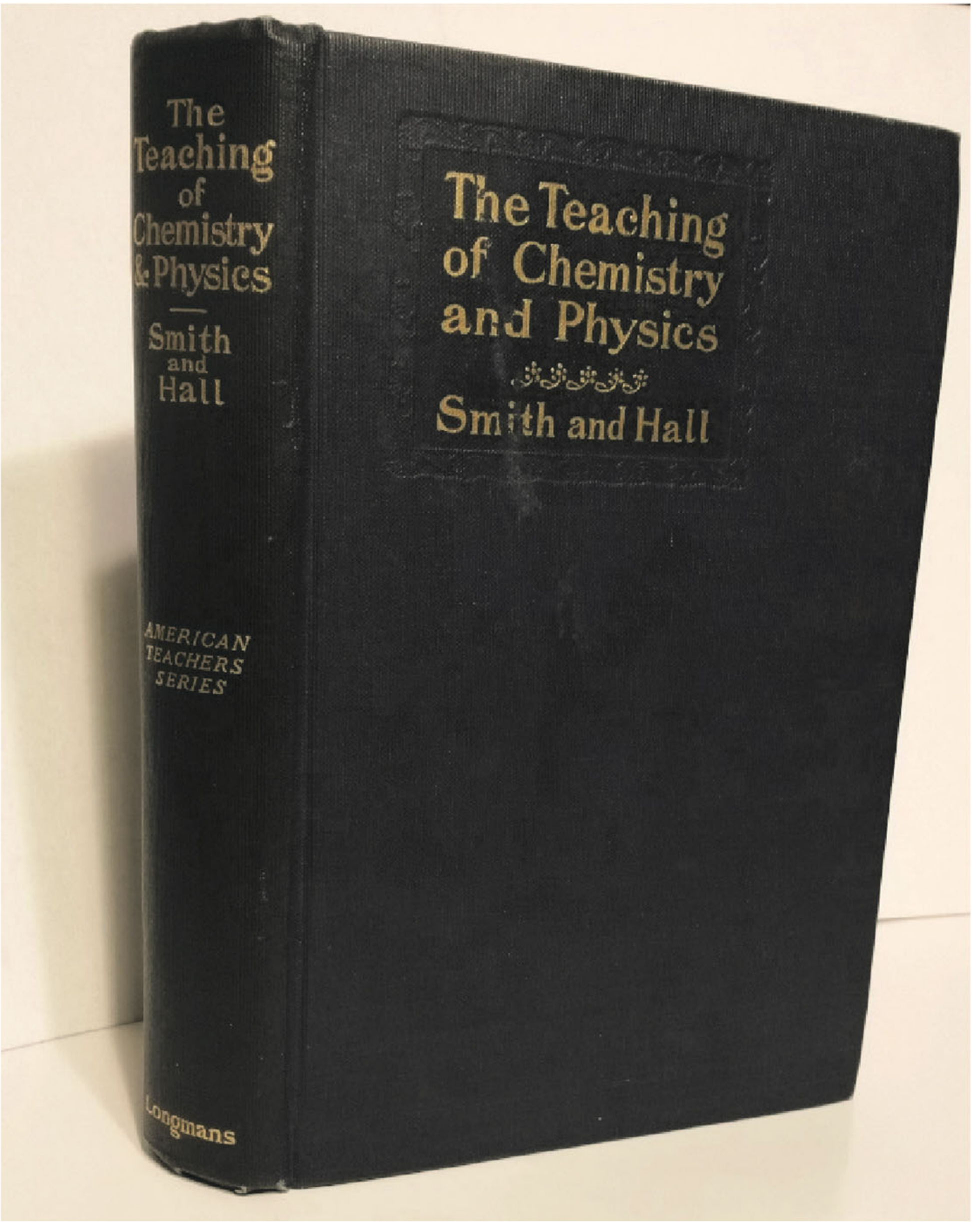


equatorial ring within the glass. Pass a string through the longest diameter of an onion *c*, and rotate; the onion gradually changes its position so as to rotate on its shortest axis. (Explain.) A chain *b* assumes on rotation a similar position.



In 1887, Harvard University published a descriptive list of experiments compiled by physicist and science educator E. H. Hall. These were intended for secondary-school students planning to apply to Harvard. This list helped drive the very rapid expansion of laboratory instruction in U.S. secondary schools.

The experiment designs were based on Hall's belief in inquiry-based learning.



E.H. Hall:

"I would keep the pupil just enough in the dark as to the probable outcome of his experiment, just enough in the attitude of discovery, to leave him unprejudiced in his observations…the experimenter should hold himself in the attitude of genuine inquiry."

[The Teaching of Chemistry and Physics in the Secondary School (A. Smith and E. H. Hall, 1902)]

A COLLEGE COURSE

OF

LABORATORY EXPERIMENTS IN GENERAL PHYSICS

BY

SAMUEL W. STRATTON,
Associate Professor of Physics in the University of Chicago

AND

ROBERT A. MILLIKAN,
Associate in Physics in the University of Chicago

[Nobel Laureate]

CHICAGO
The University of Chicago Press
1898

the wave-length thus obtained, determine both the pitch of the note produced and the velocity of sound in glass. Compare the result with that given by theory, viz.: $V=\sqrt{\frac{E}{D}}$, in which E is Young's Modulus for glass. Replace the glass by a steel or brass rod and repeat.

c) *In gases.* Through the stopcock *o* introduce into the tube carbon dioxide in place of air and determine the velocity of sound in this gas. Compare the result with that obtained by theory, viz.: $V=\sqrt{\frac{K\,P\,(1+c\,t)}{D_o}}$. K is the ratio of the specific heats of the gas by constant pressure and by constant volume.[1] This ratio may be taken from a table (see Whiting p. 861).

Questions: (1) Why is the modulus of elasticity of a gas, the temperature remaining constant, simply the existing pressure?

(2) Why do not barometric changes affect the velocity of sound? Show how the formula $V_t = 332.\sqrt{1 + .00367\,t}$ is obtained?

(3) What overtones are shown by *a* (1) to be possible in a closed pipe; by *a* (2) in an open pipe?

(4) Explain why the wave-length of the fundamental of a closed pipe is four times the length of the pipe; of an open pipe, twice the length?

RECORD OF EXPERIMENT 33.

Bar. h't = ——— Tem. = ———. Den. of air = ——— of Co_2 = ———

a) (1) pm = ——— pn = ——— ∴ mn = ——— Rate of fork = ———

∴ Vel. in air = ———. Calc'd value = ———. Correct'n to pm = ———

(2) 1st resonant length = ——— 2d = ——— Dif. = ———

∴ Vel. in air = ——— - - - Correction to 1st length = ———

b) Length of m = ———, No. nodes = ——— Total distance = ———

∴ ½ wave length = ——— ∴ Vel. in glass = ——— Calc'd value = ———

c) ½ w.-l. in CO_2 = ——— ∴ Vel. = ——— Calc'd value = ———

Name——————————— Date———————

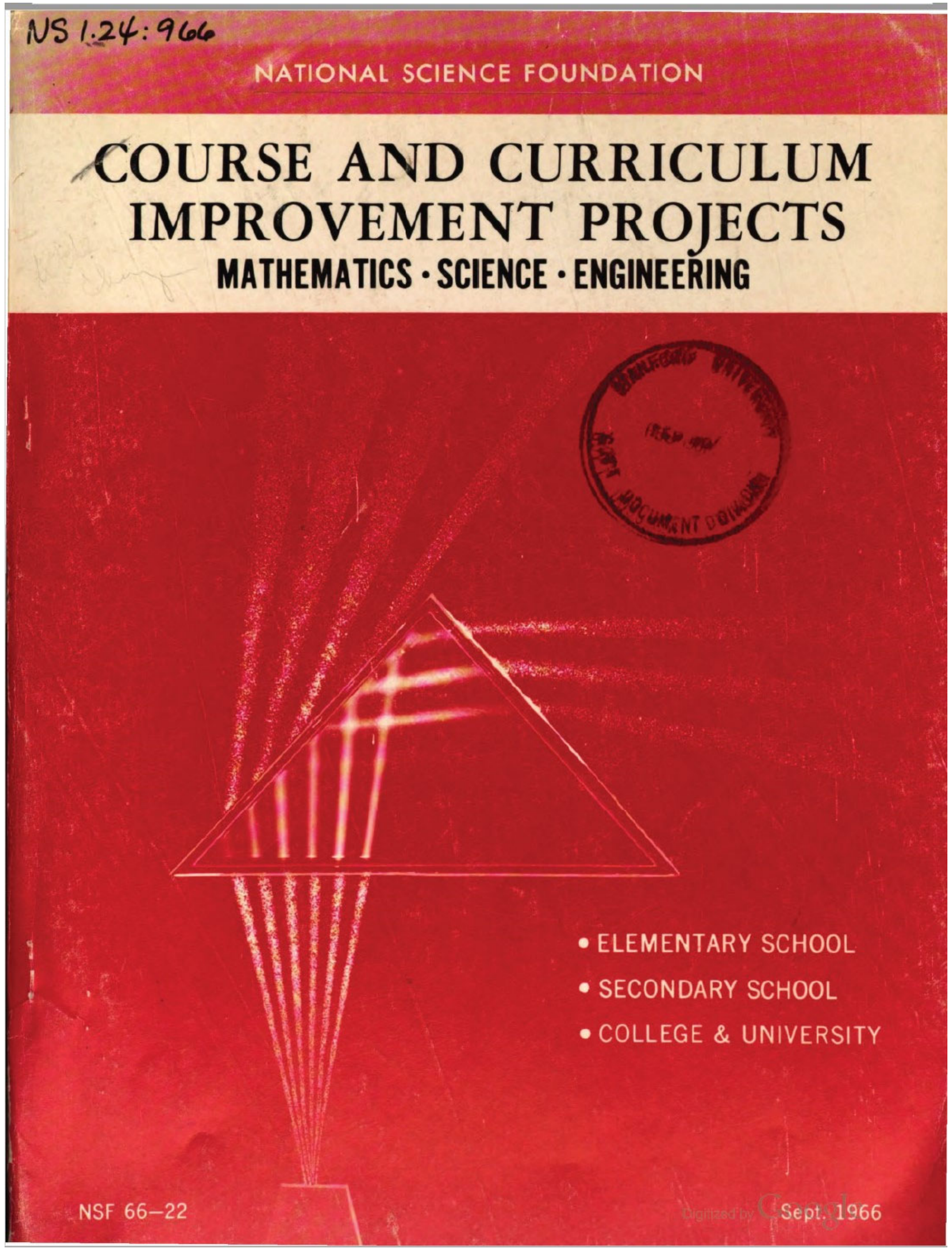
[1] Deschanel, p. 881 and 475–6.

Transition: ≈1915 to 1955

- Early science educators advocated instruction based on hands-on investigation and discovery; however…
- …between approximately 1915 and 1955, these methods became less popular, at the same time that university research scientists withdrew participation from efforts at instructional reform.

1950s: A New Beginning

In the 1950s and 1960s, university scientists re-entered the scene, and attempted to transform STEM instruction

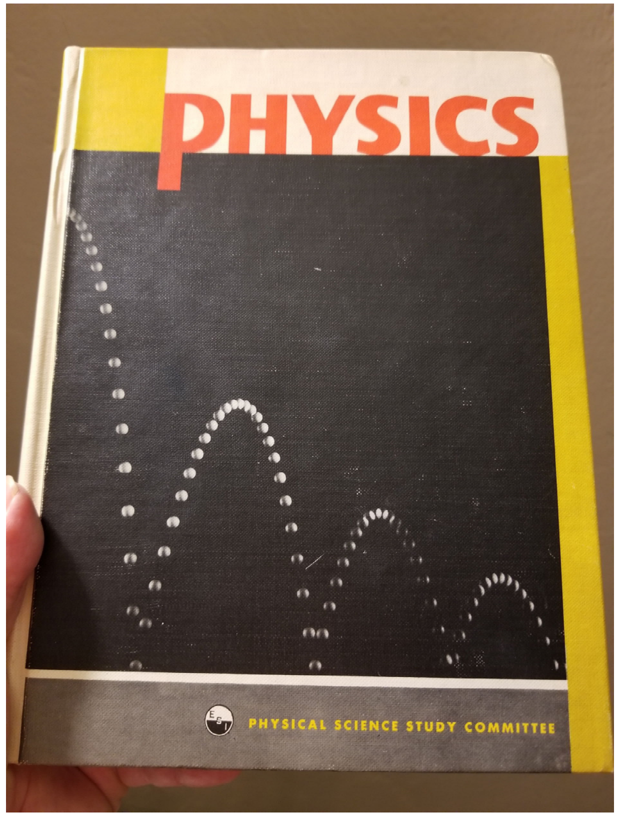


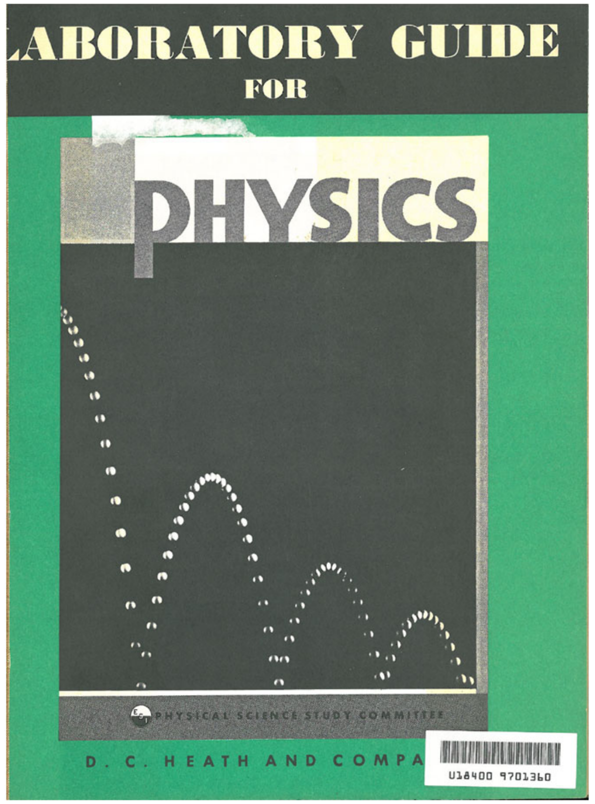
In the 1950s and 1960s, shocked into action by the launch of the Soviet Union’s Sputnik satellite, the U.S. Congress allocated many millions of dollars for the improvement of science education in the United States.

Funding was provided to support many course and curriculum development efforts at the elementary and secondary level.

1960: Physical Science Study Committee (PSSC)

- University physicists designed a new secondary school physics course
- The textbook strongly emphasized conceptual understanding
- Laboratory exercises were lightly guided, leaving much up to the student
- PSSC became one of the models for future research-based instruction





Similar well-funded projects were carried out in mathematics and other science disciplines:

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CHEMICAL BOND APPROACH PROJECT

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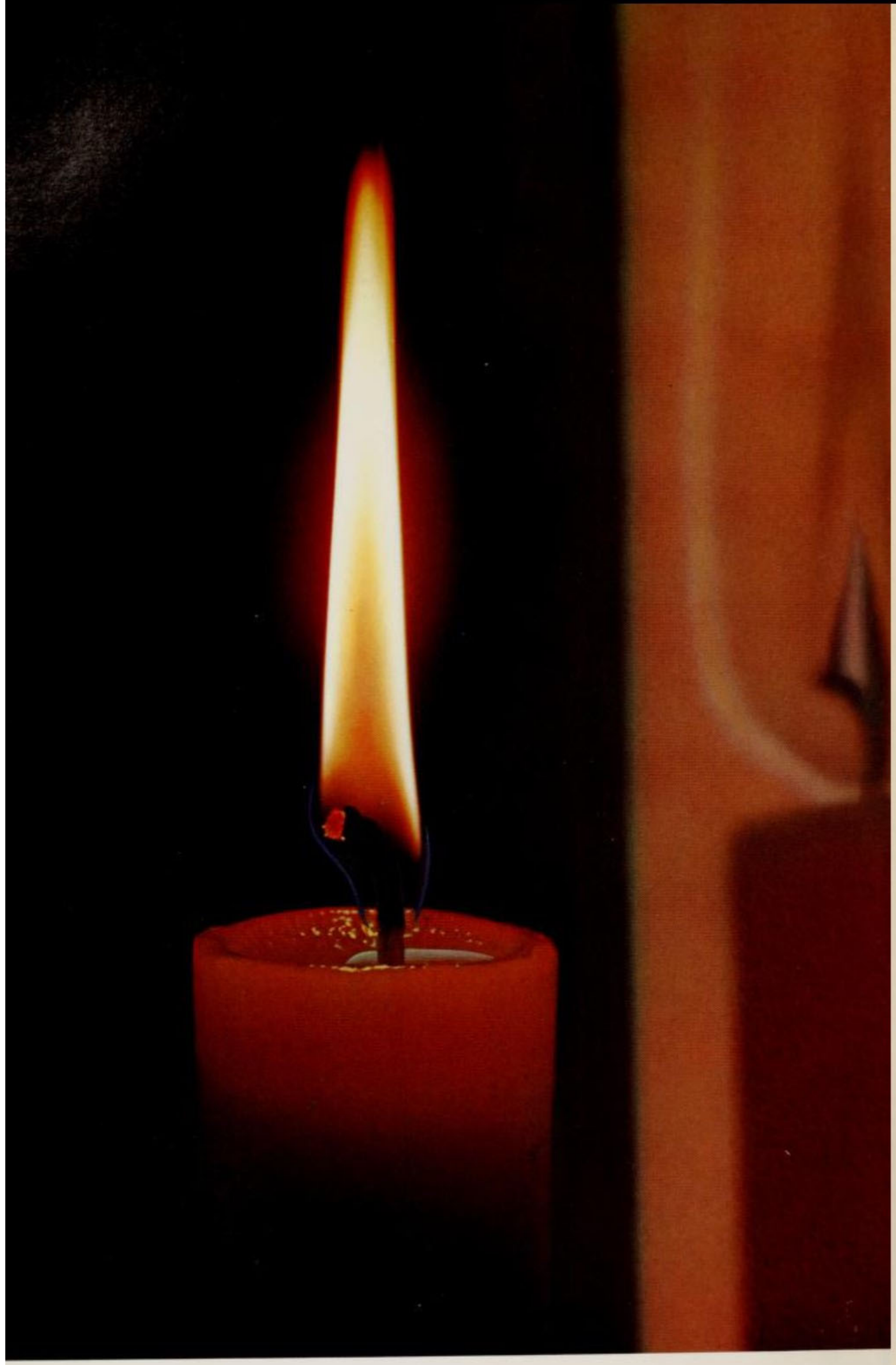

THE CANDLE—ILLUMINATING CHEMISTRY

The CHEM Study *Story*

RICHARD J. MERRILL
Executive Director, CHEM Study, 1962–1965
University of California, Berkeley, California

DAVID W. RIDGWAY
Executive Director, CHEM Study
University of California, Berkeley, California

With a Foreword by

GLENN T. SEABORG
United States Atomic Energy Commission,
Washington, D.C.

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W. H. FREEMAN AND COMPANY
San Francisco

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student's manual

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AND
FIELD INVESTIGATIONS

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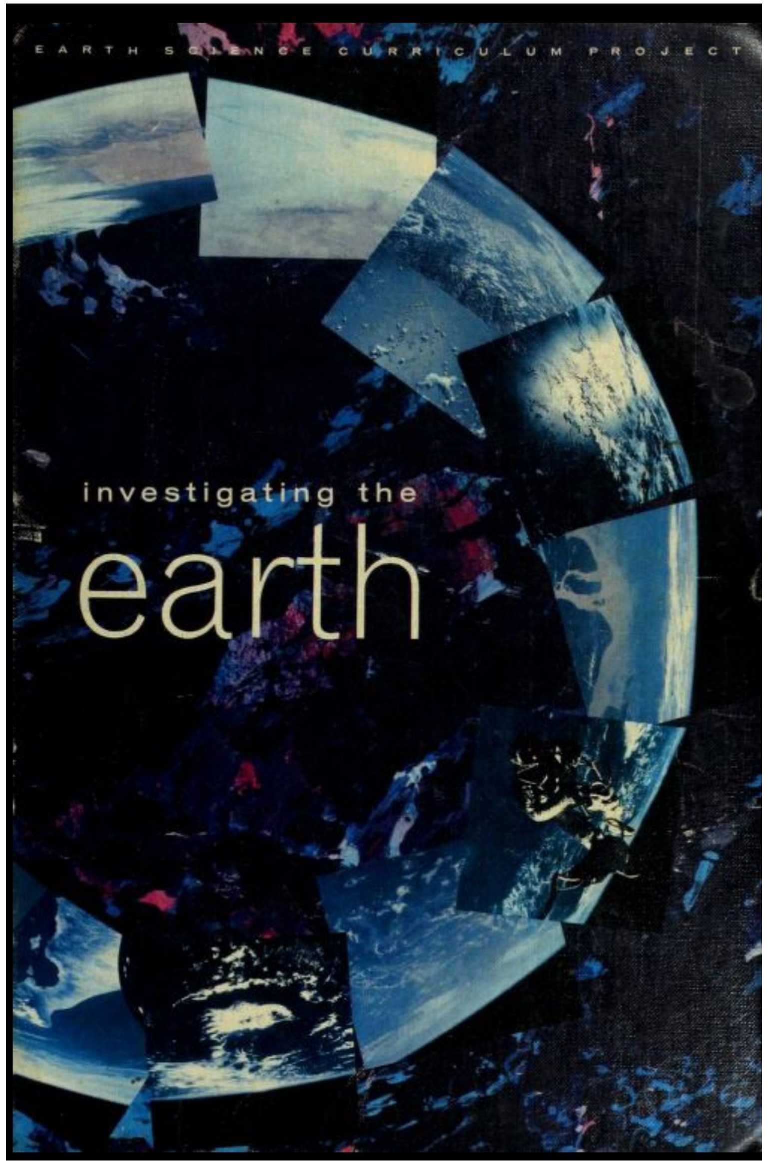

investigating the earth

EARTH SCIENCE CURRICULUM PROJECT

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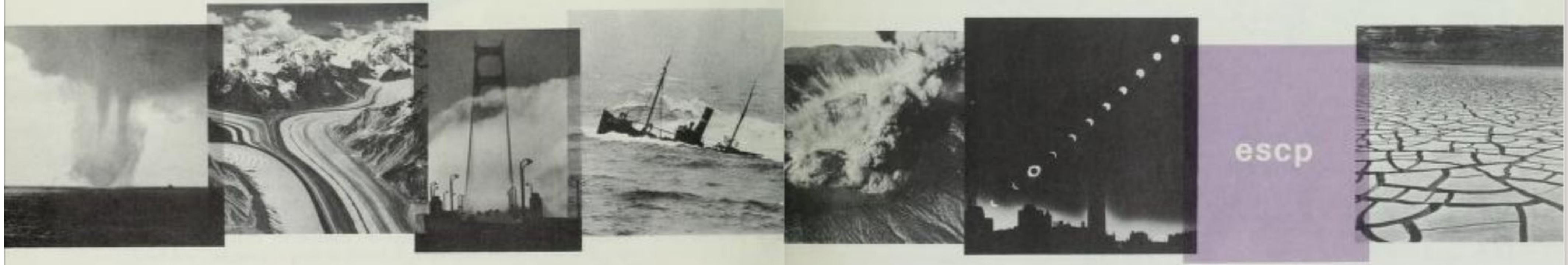

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SCHOOL MATHEMATICS STUDY GROUP

MATHEMATICS FOR HIGH SCHOOL

FIRST COURSE IN ALGEBRA (Part 1)

COMMENTARY FOR TEACHERS

(preliminary edition)

Outcome of the 1950s reforms

- The new STEM curricula of the 1950s and 1960s had an enormous influence on future curriculum development efforts; however…
- …they had only limited effectiveness in improving student learning.
- They employed active-learning instructional methods, but *they lacked support from research* targeted at students’ thinking in STEM.

1950s-1960s: Arnold Arons

During the 1950s, Arnold Arons developed a highly innovative physics course at Amherst College, requiring students to explain their reasoning in great detail.

Structure, Methods, and Objectives of the Required Freshman Calculus-Physics Course at Amherst College

A. B. Arons
Amherst College, Amherst, Massachusetts

(Received, February 24, 1959)

A description is given of the Amherst freshman calculus-physics course with specific examples of test questions, term paper assignments, and laboratory instructions. A few quotations are given from student papers, and fairly detailed syllabi of the mathematics and physics work are included.

I. INTRODUCTION

A FRESHMAN calculus-physics course, required of all students, was instituted at Amherst College in 1947 as part of a major postwar curriculum revision.[1]

The objective was a course which would deal with the main stream of physical concepts, laws, and ideas; would examine these matters in some depth, with sophistication and with adequate mathematical tools; would consider logical, epistemological, philosophical, and historical aspects; and would be of such nature in subject matter and content as to be simultaneously a proper introductory course for science majors, a terminal course in physical science for nonscience majors, and a "general education" course for both groups.

In the first few years of operation, the "common experience" aspects were compromised to some extent, and the freshman class was divided into two halves of higher and lower aptitude as indicated by various C.E.E.B. test scores. The lower aptitude group proceeded at a somewhat slower pace in mathematics and received a more descriptive development in physics than did the higher aptitude group. As the experiment progressed and more confidence developed, the separation was eliminated, and for the past few years the entire class has been treated as a single unit, all students taking the same program in calculus and physics.

A description of the course in its present state

[1] G. Kennedy, *Education at Amherst* (Harper and Brothers, New York, 1955).

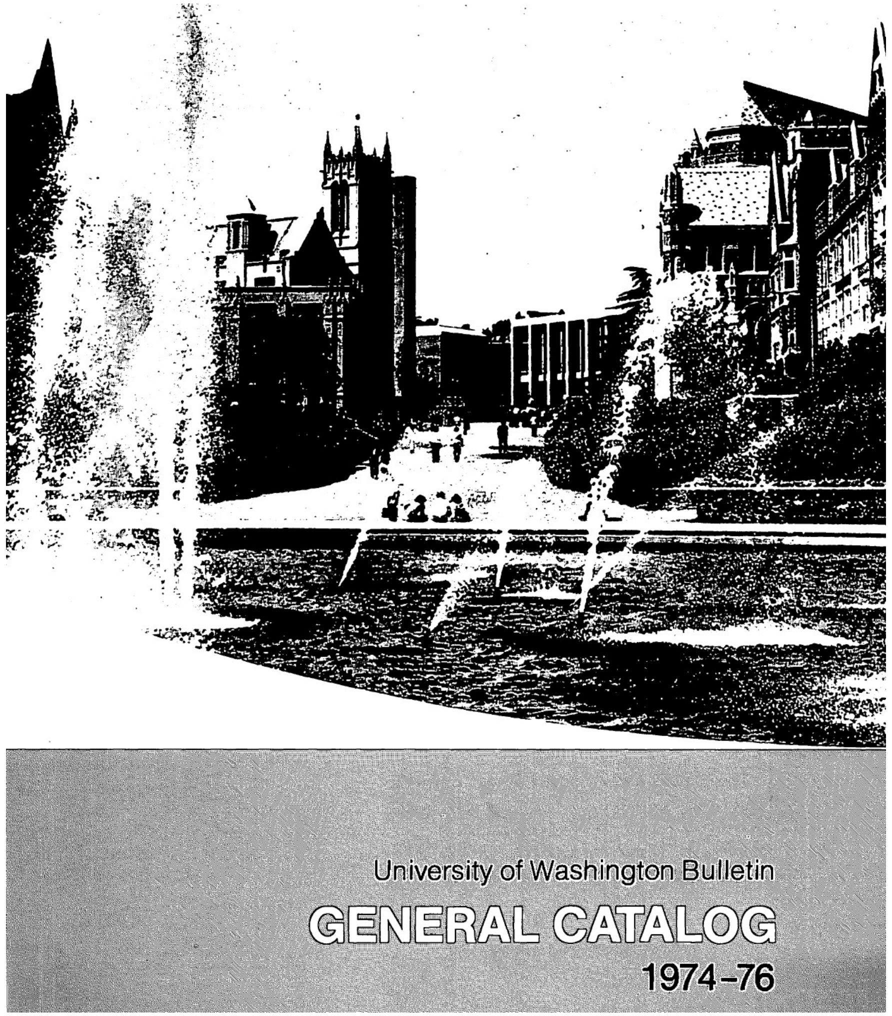
Am. J. Phys. 27, 658-666 (1959)

Arons to U. Washington; McDermott joins him

- 1968: Arons joined the faculty at the University of Washington to develop an inquiry-based physics course for elementary school teachers.
- 1969: After obtaining her Ph.D. in nuclear physics and beginning to teach, Lillian McDermott joined Arons at the University of Washington. Together, they created courses and curricular materials that used Socratic questioning to build students' conceptual understanding and reasoning skill.

Beginning of Physics Education Research

1973: McDermott hired as tenure-track Assistant Professor at UW; begins to guide three *physics* Ph.D. students in systematic research on the teaching and learning of physics at the university level, probably the first time this had happened anywhere.



PHYSICS
215 Physics

Physics is the study of the fundamental structure of matter and the interactions of its constituents, as well as the basic natural laws governing the behavior of matter.

Faculty

Ernest M. Henley, Chairman; Adelberger, Arons, Baker, Bali, Blair, Bodansky, Boulware, Brakel (emeritus), Brown, Cahn, Clark, Cook, Cramer, Dash, Davisson, Dehmelt, Fain, Farwell, Fortson, Geballe, Gerhart, Halpern, Henderson (emeritus), Henley, Higgs (emeritus), Ingalls, Kenworthy (emeritus), Kirkpatrick, Lee, Lord, Lubatti, $\boxed{\text{L. McDermott,}}$ M. McDermott, Moriyasu, Neddermeyer (emeritus), Peters, Puff, Rothberg, Sabo, Sanderman (emeritus), Schick, Schmidt, Stern, Streib, Uehling (emeritus), Vilches, Weis, Weitkamp, Wilets, Williams, Young. D. Boulware, graduate program adviser.

Other Early Research on STEM Learning

- Laurence Viennot (1974-79): Research on French university physics students
- Robert Karplus (1975): Research to improve STEM students’ reasoning
- Frederick Reif (1976): Research on students’ reasoning patterns in order to develop instructional methods for improving problem-solving skill
- John Clement (1982): Investigate students’ ideas in mechanics
- Ibrahim Halloun and David Hestenes (1985): Investigation of students’ ideas in Newtonian mechanics; development of diagnostic instrument
- Ronald Thornton and David Sokoloff (1990): Physics curriculum development using computer technologies based on research into students’ ideas

Teaching general learning and problem-solving skills*

F. Reif, Jill H. Larkin, and George C. Brackett
Department of Physics and Group in Science and Mathematics Education, University of California, Berkeley, California 94720
(Received 7 May 1975; revised 9 September 1975)

This article describes the investigation and teaching of two general cognitive skills important

EUR. J. SCI. EDUC., 1979, VOL. 1, NO. 2, 205–221

Spontaneous Reasoning in Elementary Dynamics

L. Viennot, University of Paris VII, France

Students' preconceptions in introductory mechanics

John Clement
Department of Physics and Astronomy, University of Massachusetts, Amherst, Massachusetts 01003
(Received 14 August 1980; accepted for publication 18 March 1981)
Data from written tests and videotaped problem-solving interviews show that many physics

The initial knowledge state of college physics students

Ibrahim Abou Halloun[a] and David Hestenes
Department of Physics, Arizona State University, Tempe, Arizona 85287
(Received 1 August 1984; accepted for publication 28 January 1985)
An instrument to assess the basic knowledge state of students taking a first course in physics has been designed and validated. Measurements with the instrument show that the student's initial qualitative, common sense beliefs about motion and causes has a large effect on performance in physics, but conventional instruction induces only a small change in those beliefs.

ADAPT Program – Accent on Developing Abstract Processes of Thought

Workshop Materials: Physics Teaching and the Development of Reasoning

University of Nebraska - Lincoln *Year* 1975

Workshop on Physics Teaching and the Development of Reasoning: Complete Set of Modules

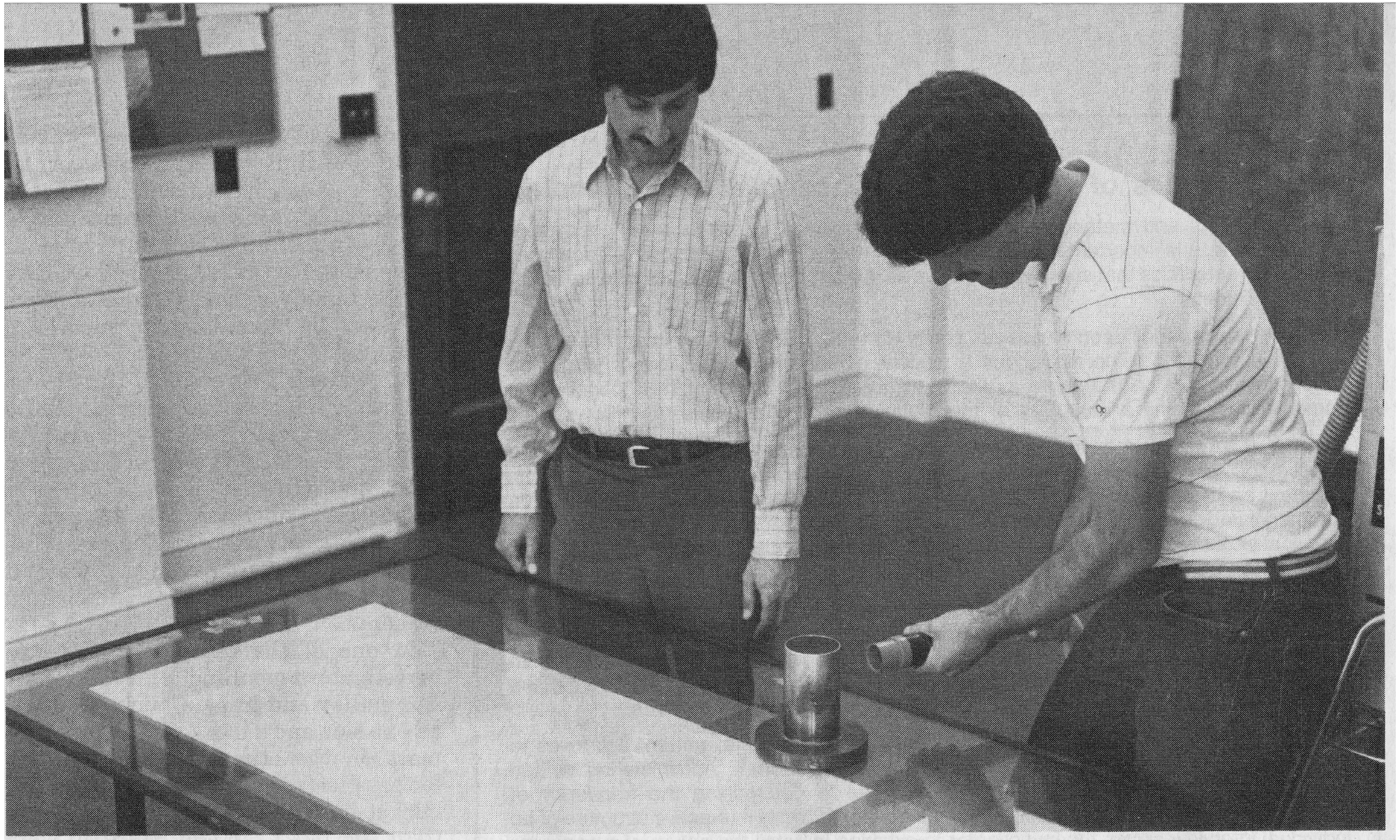
Francis P. Collea* Robert Fuller† Robert Karplus‡
Lester G. Paldy** John W. Renner††

Learning motion concepts using real-time microcomputer-based laboratory tools

Ronald K. Thornton
Center for Science and Mathematics Teaching, Tufts University, Medford, Massachusetts 02155
David R. Sokoloff
Department of Physics, University of Oregon, Eugene, Oregon 97403
(Received 5 September 1989; accepted for publication 27 November 1989)
Microcomputer-based laboratory (MBL) tools have been developed which interface to Apple II

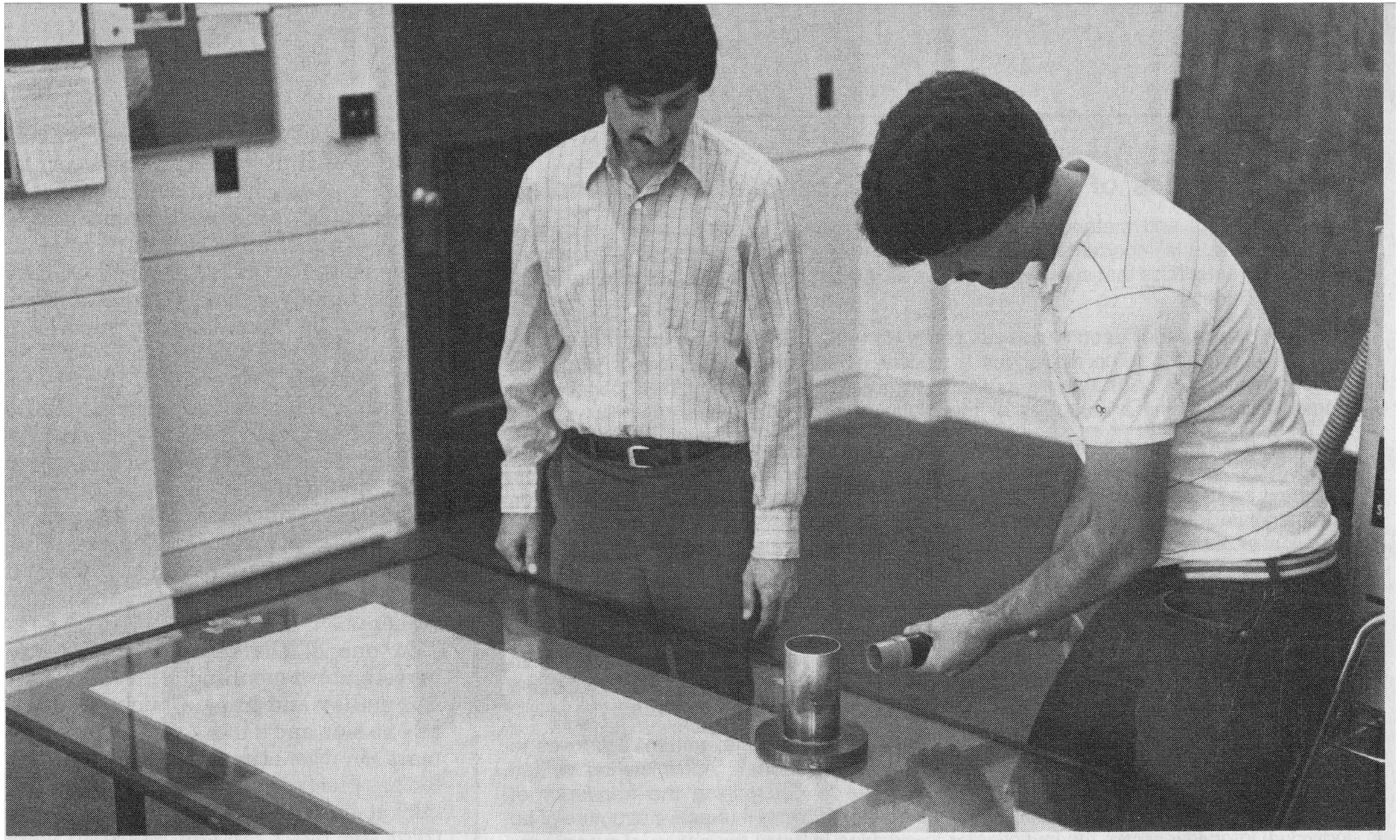
McDermott’s Research Program

- Recognize that *research is required* to best decide “the right questions to ask” during active-learning instruction.
- Recognize that students’ difficulties often originate from weak conceptual understanding *and* underdeveloped reasoning skills; researchers must investigate both simultaneously.
- To investigate students’ thinking in depth, ask them to explain their reasoning while engaged in interpreting physics experiments: “Individual Demonstration Interview.”
- Develop instructional materials that are *rigorously and repeatedly tested*, to ensure they actually help students learn.



Investigating student understanding of force. Ronald Lawson (left) is asking a student to deflect a moving dry-ice puck at a 45° angle to its direction of motion using a blast of air from the hose; the student's reactions and comments will be recorded. In this research project, conducted by the Physics Education Group at the University of Washington, students were asked to perform this and similar tasks in individual demonstration interviews. As in other research conducted by the group, the major criterion used to assess conceptual understanding was the ability to apply concepts learned in class to actual physical systems.

"Individual Demonstration Interview": Investigator and student "one-on-one"



Investigating student understanding of force. Ronald Lawson (left) is asking a student to deflect a moving dry-ice puck at a 45° angle to its direction of motion using a blast of air from the hose; the student's reactions and comments will be recorded. In this research project, conducted by the Physics Education Group at the University of Washington, students were asked to perform this and similar tasks in individual demonstration interviews. As in other research conducted by the group, the major criterion used to assess conceptual understanding was the ability to apply concepts learned in class to actual physical systems.

Student explains his thinking while carrying out experiment (~1980)

These were among the very first articles to report detailed research on the learning of physics by university students

Investigation of student understanding of the concept of velocity in one dimension

David E. Trowbridge[a] and Lillian C. McDermott
Department of Physics, University of Washington, Seattle, Washington 98195
(Received 25 February 1980; accepted 20 May 1980)

This paper describes a systematic investigation of the understanding of the concept of velocity among students enrolled in a wide variety of introductory physics courses at the University of Washington. The criterion selected for assessing understanding of a kinematical concept is the ability to apply it successfully in interpreting simple motions of real objects. The primary data source has been the individual demonstration interview in which students are asked specific questions about simple motions they observe. Results are reported for the success of different student populations in comparing velocities for two simultaneous motions. It appears that virtually every failure to make a proper comparison can be attributed to use of a position criterion to determine relative velocity. Some implications for instruction are briefly discussed.

I. INTRODUCTION

The Physics Education Group at the University of Washington has been engaged for several years in a systematic study of the ways in which students in introductory college physics courses think about motion. The degree of difficulty of the courses ranges from compensatory (for academically disadvantaged students) to calculus based (for physics, engineering, and mathematics majors). This article is the first of two devoted to the kinematical concepts. The present paper reports on the ability of students to apply the concept of velocity in interpreting simple motions of real objects. A subsequent article will discuss student under-

critical to the study of almost all of p
has been research by other investiga
of conceptual understanding of dynar
studies on kinematics have appeare
beginning our investigation with the
we hoped not only to identify speci
have with kinematics but also to g
possible kinematical origins of
namics.

B. Criterion for understanding

An important distinction must

1980

1981

Investigation of student understanding of the concept of acceleration in one dimension

David E. Trowbridge[a] and Lillian C. McDermott
Department of Physics, University of Washington, Seattle, Washington 98195
(Received 15 April 1980; accepted 23 July 1980)

This paper describes a systematic investigation of the understanding of the concept of acceleration among students enrolled in a variety of introductory physics courses at the University of Washington. The criterion for assessing understanding of a kinematical concept is the ability to apply it successfully in interpreting simple motions of real objects. The main thrust of this study has been on the qualitative understanding of acceleration as the ratio $\Delta v/\Delta t$. The primary data source has been the individual demonstration interview in which students are asked specific questions about simple motions they observe. Results are reported for the success of different student populations in comparing accelerations for two simultaneous motions. Failure to make a proper comparison was due to various conceptual difficulties which are identified and described. Some implications for instruction are briefly discussed.

I. INTRODUCTION

The Physics Education Group at the University of Washington has been engaged for several years in a systematic study of the ways in which students in introductory college physics courses think about motion. The degree of difficulty of the courses ranges from compensatory (for academically disadvantaged students) to calculus based (for

angle to the horizontal. The accelerations of the balls can be varied by using channels of different widths as shown in Fig. 1. Thus prior knowledge about the dependence of acceleration on slope yields no clues for making correct comparisons. A mechanism for releasing the balls automatically insures that the motions are reproducible.

The interviews are conducted according to a standard questioning format but at any point the interviewer may

1987

Student understanding of the work-energy and impulse-momentum theorems

Ronald A. Lawson[a] and Lillian C. McDermott
Department of Physics, FM-15, University of Washington, Seattle, Washington 98195

(Received 4 September 1986; accepted for publication 17 November 1986)

Student understanding of the impulse-momentum and work-energy theorems was
performance on tasks requiring the application of these relationships to the analysis
motion. The participants in the study were undergraduates enrolled in either the hon
a calculus-based introductory physics course or in the regular algebra-based course.
were asked to compare the changes in momentum and kinetic energy of two frictio
pucks as they moved rectilinearly under the influence of the same constant force. T
the investigation revealed that most of the students were unable to relate the algebra
learned in class to the simple motion that they observed.

A conceptual approach to teaching kinematics

Mark L. Rosenquist[a] and Lillian C. McDermott
Department of Physics FM-15, University of Washington, Seattle, Washington 98195

(Received 21 February 1986; accepted for publication 21 May 1986)

Results from research on student understanding of velocity and acceleration hav
guide the development of a conceptual approach to teaching kinematics. This paper
instruction based on the observation of actual motions can help students: (1) develo
understanding of velocity as a continuously varying quantity, of instantaneous velo
and of uniform acceleration as the ratio of the change in instantaneous velocity to the elapsed time; (2) distinguish the concepts of position, velocity, change of velocity, and acceleration from one another; and (3) make connections among the various kinematical concepts, their graphical representations, and the motions of real objects. Instructional strategies designed to address specific difficulties identified in the investigation are illustrated by example.

I. INTRODUCTION

The Physics Education Group at the University of

II. UNDERSTANDING INSTANTANEOUS VELOCITY AS A LIMIT

1987

Student difficulties in connecting graphs and physics: Examples from kinematics

Lillian C. McDermott, Mark L. Rosenquist,[a] and Emily H. van Zee
Department of Physics, University of Washington, Seattle, Washington 98195

(Received 21 February 1986; accepted for publication 21 May 1986)

Some common errors exhibited by students in interpreting graphs in physics are illustrated by examples from kinematics. These are taken from the results of a descriptive study extending over a period of several years and involving several hundred university students who were enrolled in a laboratory-based preparatory physics course. Subsequent testing indicated that the graphing errors made by this group of students are not idiosyncratic, but are found in different populations and across different levels of sophistication. This paper examines two categories of difficulty identified in the investigation: difficulty in connecting graphs to physical concepts and difficulty in connecting graphs to the real world. Specific difficulties in each category are discussed in terms of student performance on written problems and laboratory experiments. A few of the instructional strategies that have been designed to address some of these difficulties are described.

I. INTRODUCTION

Many undergraduates taking introductory physics seem to lack the ability to use graphs either for imparting or extracting information. As part of our research on student

that many are a direct consequence of an inability to make connections between a graphical representation and the subject matter it represents. In this paper, we describe two categories of student difficulty that we have investigated: difficulty in connecting graphs to physical concepts and

1986

An investigation of student understanding of the real image formed by a converging lens or concave mirror

Fred M. Goldberg[a] and Lillian C. McDermott

Physics Education Group, Department of Physics FM–15, University of Washington, Seattle, Washington 98195

(Received 18 September 1985; accepted for publication 18 March 1986)

Student understanding of the real images produced by converging lenses and concave mirrors was investigated both before and after instruction in geometrical optics. The primary data were gathered through interviews in which undergraduates taking introductory physics were asked to perform a set of prescribed tasks based on a simple demonstration. The criterion used to assess understanding was the ability to apply appropriate concepts and principles, including ray diagrams, to predict and explain image formation by an actual lens or mirror. Performance on the tasks, especially by students who had not had college instruction in geometrical optics, suggested the presence of certain naive conceptions. Students who had just completed the study of geometrical optics in their physics courses were frequently unable to relate the concepts, principles, and ray-tracing techniques that had been taught in class to an actual physical system consisting of an object, a lens or a mirror, and a screen. Many students did not seem to understand the function of the lens, mirror, or screen, nor the uniqueness of the relationship among the components of the optical system. Difficulties in drawing and interpreting ray diagrams indicated inadequate understanding of the concept of a light ray and its graphical representation.

I. INTRODUCTION

This paper reports on an investigation of student understanding of the real image formed by a converging lens or concave mirror. This study, which extended over a period of two years (1982–1984), also included image formation by a plane mirror.[1] Conducted by the Physics Education Group at the University of Washington, this investigation was part of our ongoing effort to identify and address conceptual difficulties encountered by students taking intro-

Washington. The rest were in their second semester of algebra-based physics at West Virginia University. All the courses were taught by lecture. About half of the students had not yet studied geometrical optics in college. The other half had recently taken the course examination on that material. Of these, about half were enrolled in the optional accompanying laboratory course and had already completed the experiments in geometrical optics.

Examples of research-based curriculum development:

1. Thermodynamics
2. Buoyancy [*Statischer Auftrieb*]

Examples of research-based curriculum development:

1. Thermodynamics

Student ideas regarding entropy and the second law of thermodynamics in an introductory physics course

Warren M. Christensen[a]
Center for Science and Mathematics Education Research, University of Maine, Orono, Maine 04401

David E. Meltzer[b]
College of Teacher Education and Leadership, Arizona State University, Polytechnic Campus, Mesa, Arizona 85212

C. A. Ogilvie[c]
Department of Physics and Astronomy, Iowa State University, Ames, Iowa 50011

(Received 15 March 2008; accepted 10 June 2009)

Am. J. Phys. **77** (10), October 2009

Students enrolled in introductory physics courses are asked to respond to several questions related to entropy and the second law of thermodynamics. Based on an analysis of students' responses, new instructional materials are developed.

Question #1 of 3 questions:

An object is placed in a thermally insulated room that contains air. The object and the air in the room are initially at different temperatures.

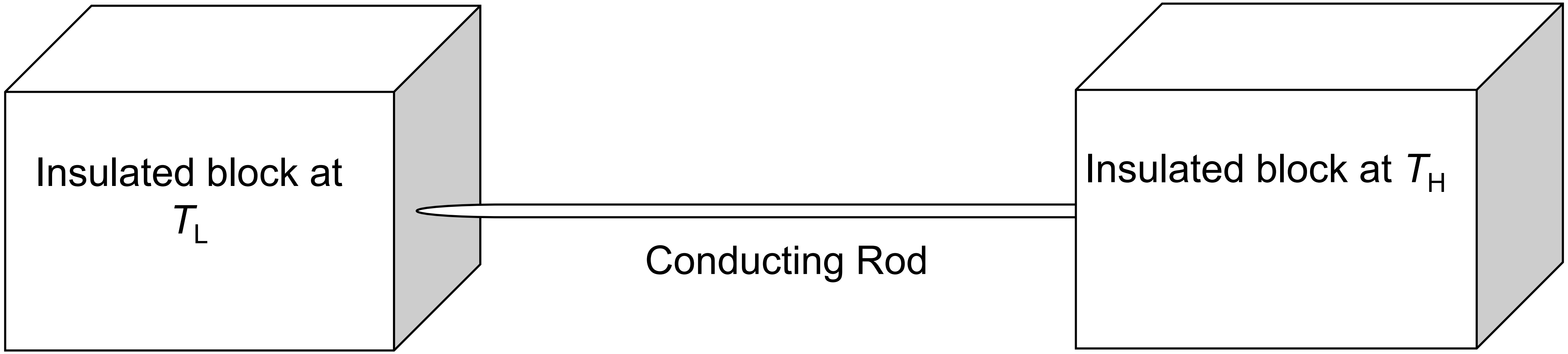
Will the total entropy (object + air) *increase*, *decrease*, or *remain the same*?

- *Correct answer:* The total entropy will increase, as it does in any heat-flow process
- Common incorrect response: Most students (71%) think that the entropy will remain unchanged.

Analysis of Students’ Reponses

- We found that most introductory students think that the total entropy will not change —that the entropy will be “conserved”
- We had not been aware that so many students had this idea
- Through individual interviews with 18 students, we realized that students were confusing the terms *entropy* and *energy*. They had previously learned that “energy is conserved” (total energy can not change in an isolated system)
- We developed instructional materials to help students understand why entropy would increase in this process

“Two-blocks” Instructional Worksheet (“Tutorial”)



Consider a slow heat transfer process between two large metal blocks at different temperatures, connected by a thin metal pipe.

- Does total energy change during the process? *[No]*
- Does total entropy change during the process? *[Yes]*

Students are guided to apply this entropy equation:

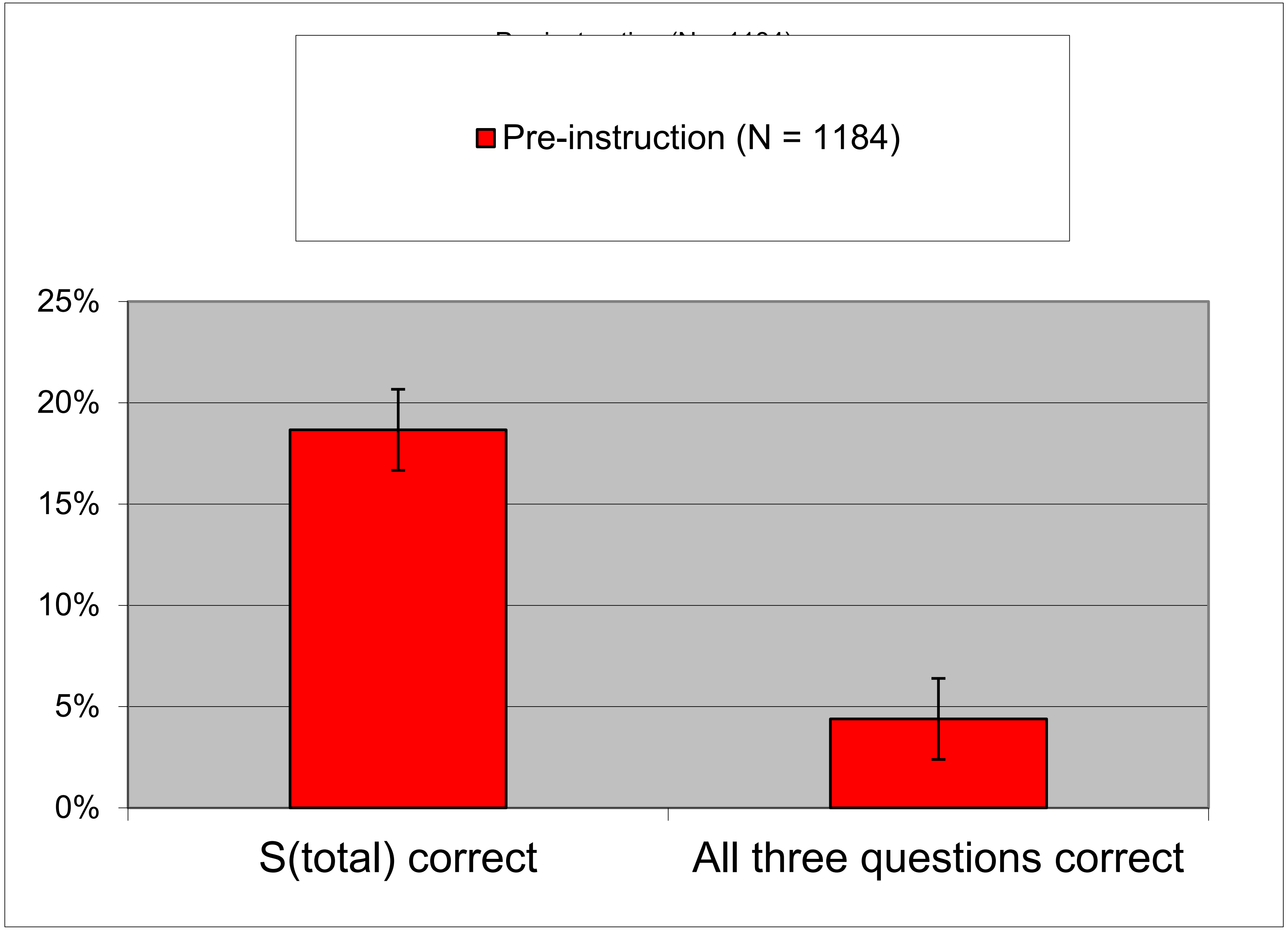
$$\Delta S = Q/T$$

ΔS = change in entropy
Q = thermal energy transfer
T = temperature

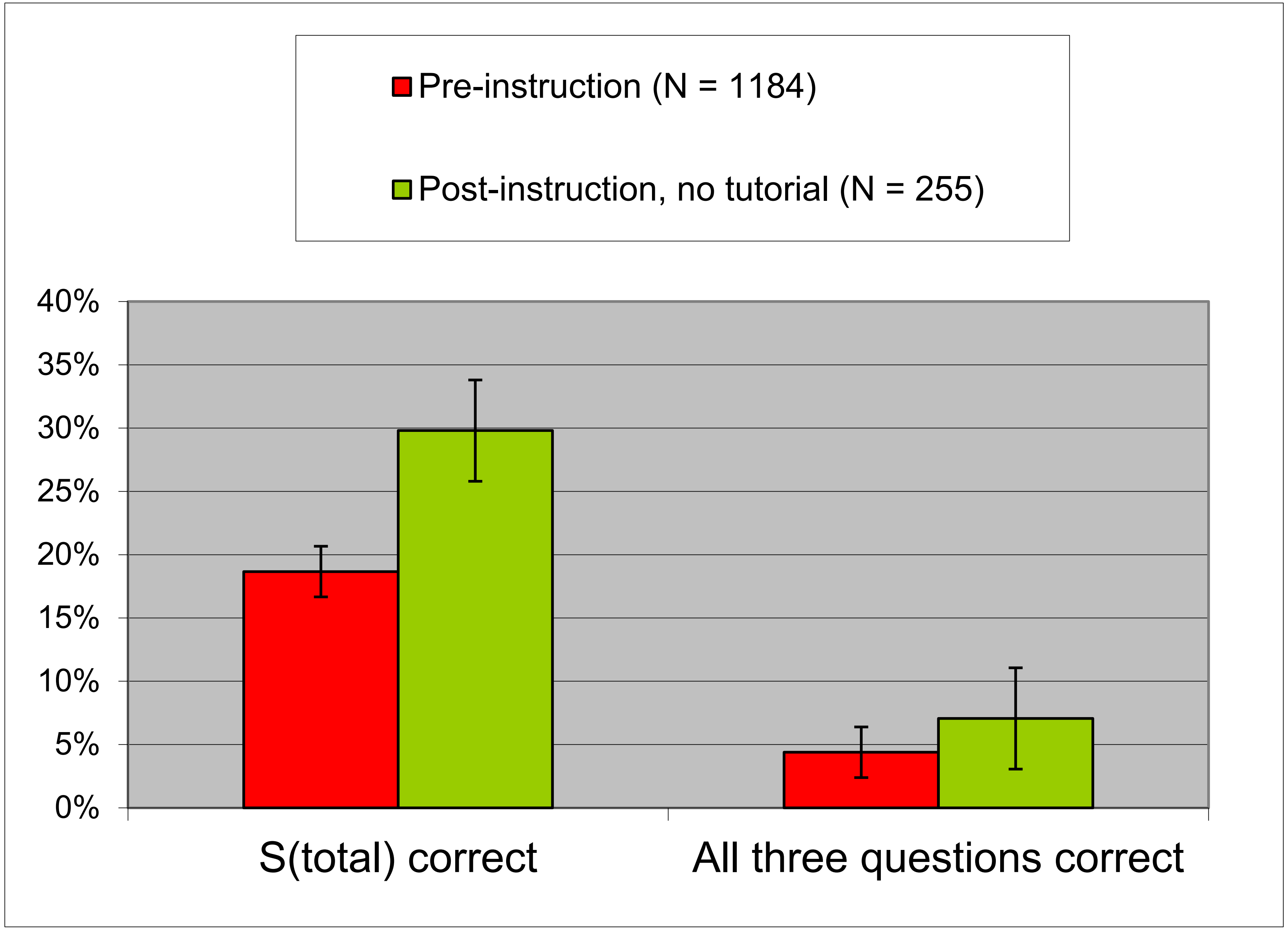
Students find that the entropy gain of the low-temperature block is *larger* than the entropy loss of high-temperature block, so:

→ *total entropy increases*

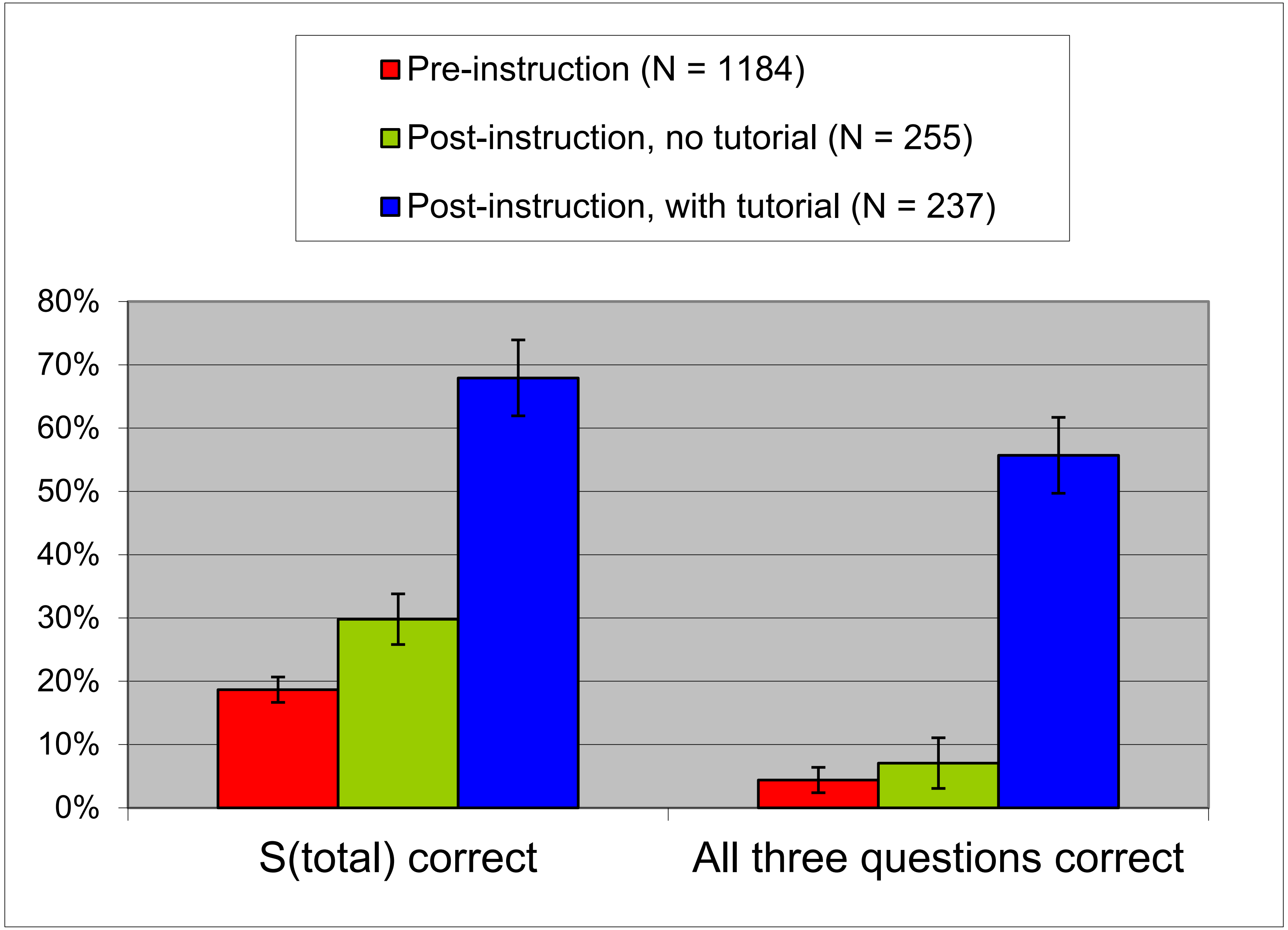
Correct responses, pre- and post-instruction



Correct responses, pre- and post-instruction



Correct responses, pre- and post-instruction



What do we gain from research on student learning?

- We learn *why* students give certain specific responses to our questions, that is, the method by which they arrive at their answers.
- We learn the precise nature of students' ideas related to specific science concepts, both potentially productive ideas and potentially *misleading* or unproductive ideas.
- We learn the *prevalence* of specific student ideas within broad categories of student populations: how widespread are they?

How do we apply research on student learning?

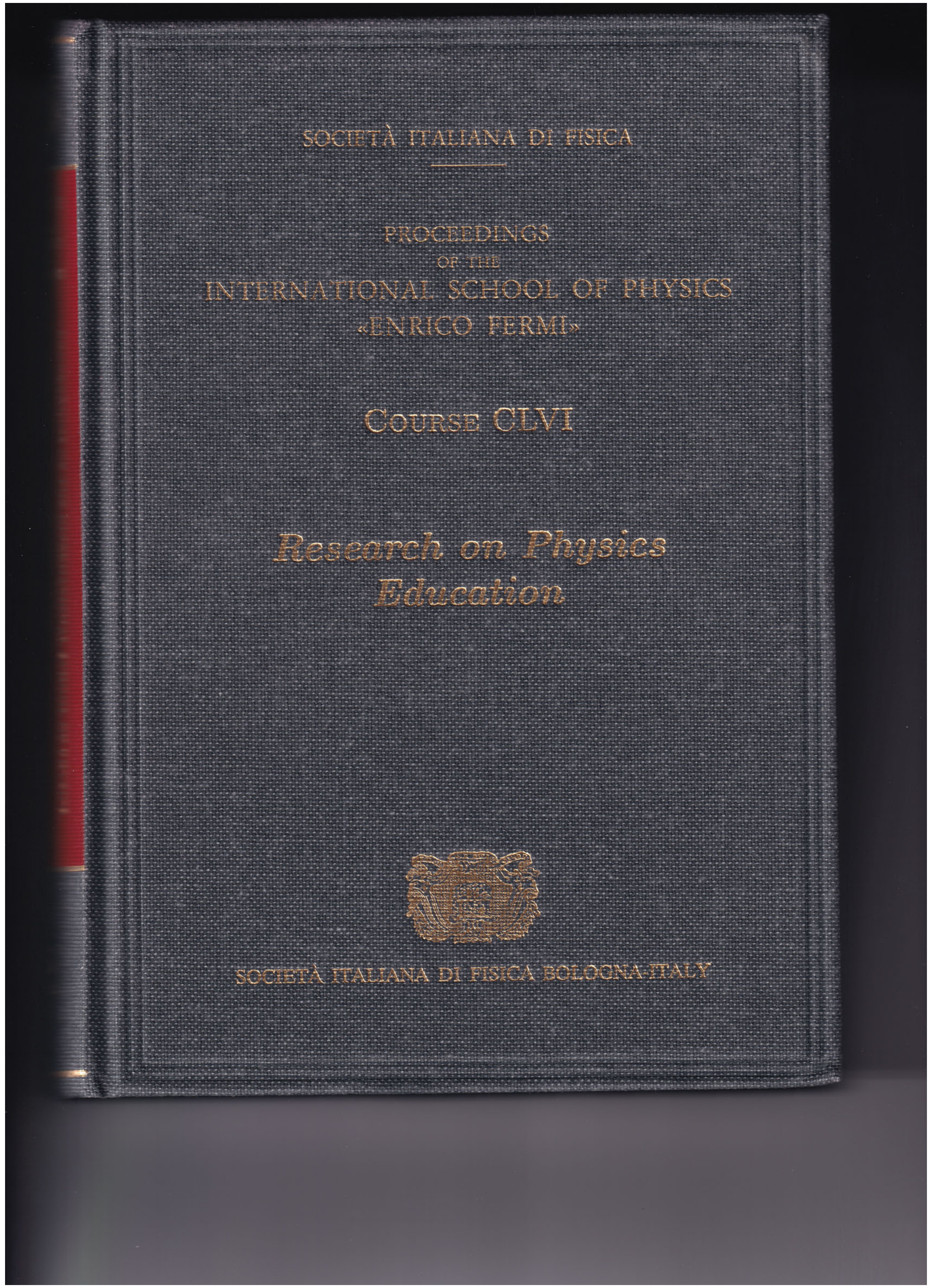
- We design sequences of questions that help students reason effectively about specific difficult concepts.
- We *monitor and test* the reactions of students to see whether their reasoning is proceeding along productive lines.
- We continually assess effectiveness of our instructional materials, and revise and re-assess to improve their utility.

Examples of research-based curriculum development:

1. Thermodynamics
2. Buoyancy

Examples of research-based curriculum development:

2. Buoyancy



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Directors of the Course

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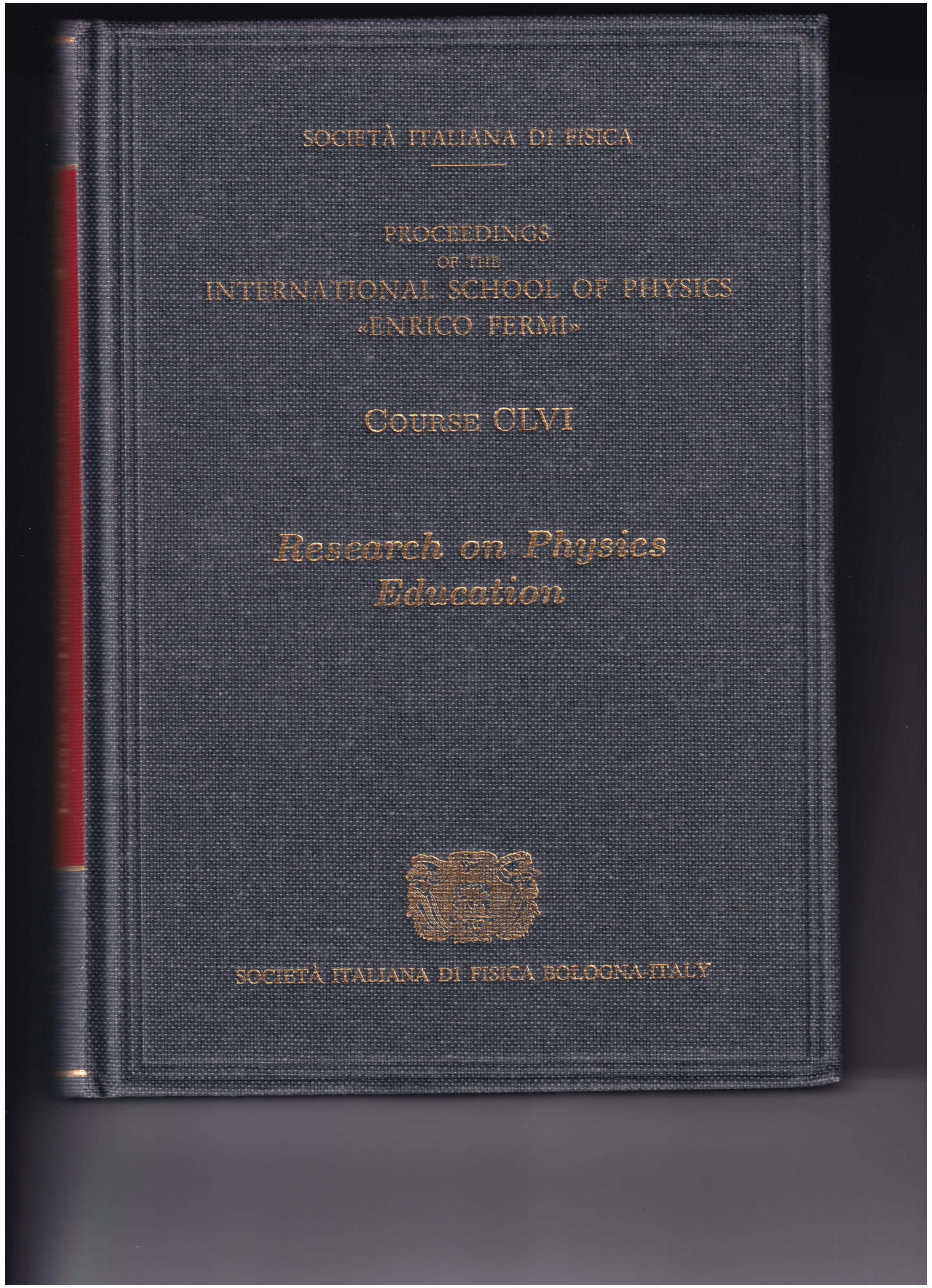


Empirical investigations of learning and teaching, part II: Developing research-based instructional materials

PAULA R. L. HERON

Department of Physics, University of Washington - Seattle, WA 98195-1560, USA

1. – Introduction

This article is the second of two that are based on lectures that described the empirical approach to physics education research of the Physics Education Group (PEG) at the University of Washington (UW). A secondary goal of the lectures was to provide an experimentalist's perspective on the development of theories of student learning and on some general issues related to experimental research. A general framework for our study of student understanding was described in the first article [1]. In this second article, the emphasis is on the role of research in developing instructional materials. An ongoing, multi-year investigation of student understanding of Archimedes' Principle provides an example. The initial investigation of student understanding is described in sect. **2**; the subsequent process of designing materials that take research findings into account is described in sect. **3**. General issues for assessing the effectiveness of instructional interventions are discussed in sect. **4**.

2. – Investigating student understanding

Our investigation began with interviews based on the behavior of a "Cartesian diver", an object whose average density, and hence its tendency to sink or float, can be varied by changing the pressure of the container in which it is sealed. The inability of students to account for the diver's behavior, despite having seen similar demonstrations in class,

[This example is based on a published paper:]

Helping students develop an understanding of Archimedes' principle. I. Research on student understanding

Michael E. Loverude,[a)] Christian H. Kautz,[b)] and Paula R. L. Heron
Department of Physics, University of Washington, Seattle, Washington 98195-1560

(Received 4 February 2002; accepted 18 July 2003)

Am. J. Phys. **71** (11), November 2003

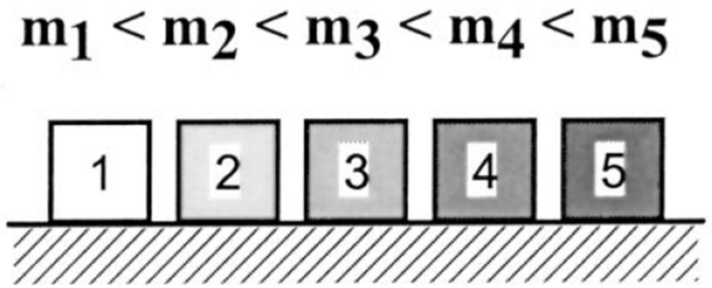
Five blocks of the same size and shape but different masses are shown at right. The blocks are numbered in order of increasing mass (*i.e.* $m_1 < m_2 < m_3 < m_4 < m_5$).

All the blocks are held approximately halfway down in an aquarium filled with water and then released. The final positions of blocks 2 and 5 are shown.

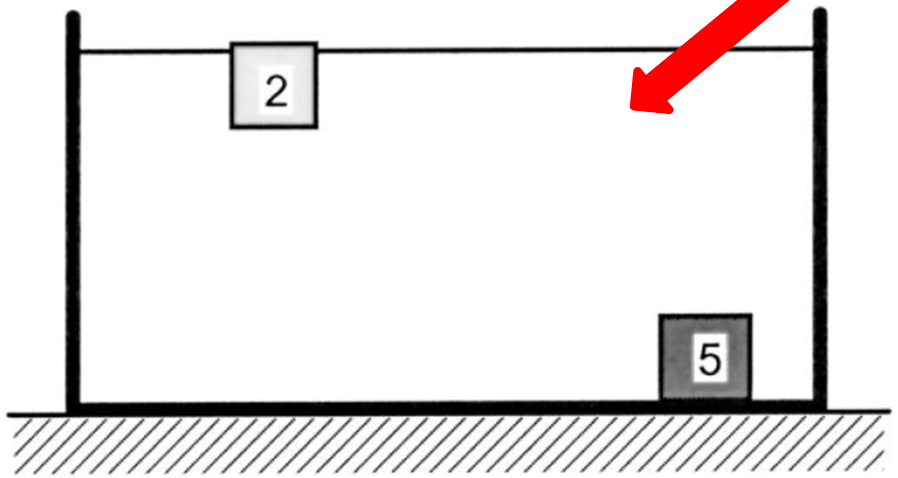
On the diagram, sketch the final positions of blocks 1, 3, and 4. Explain your reasoning.

(Assume that the water is incompressible.)

Blocks of equal volume, different mass



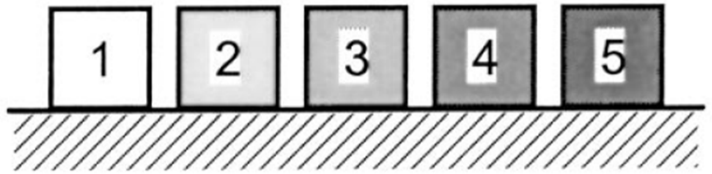
water

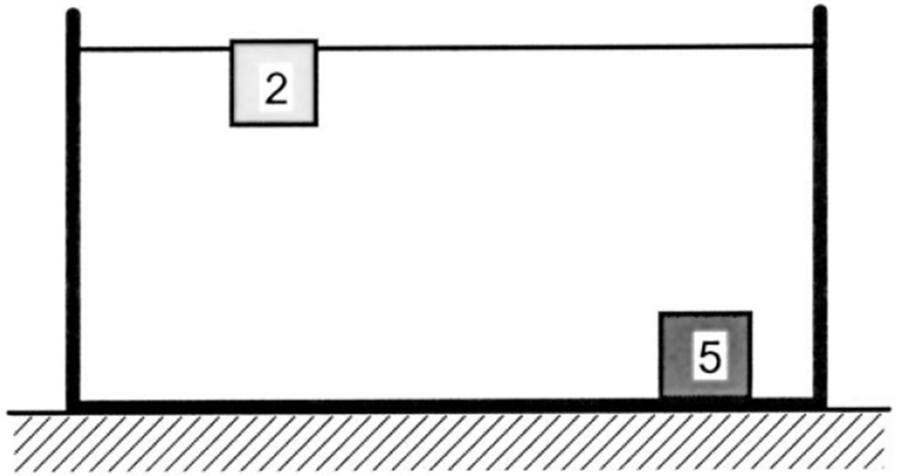


Blocks are held underneath water surface and released

On the diagram, sketch the final positions of blocks 1, 3, and 4. Explain your reasoning.

$m_1 < m_2 < m_3 < m_4 < m_5$

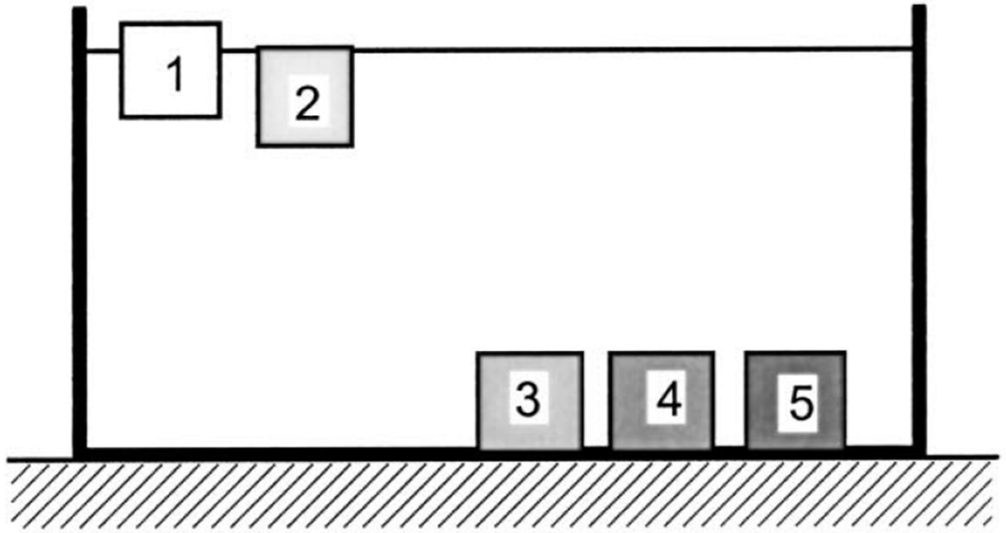


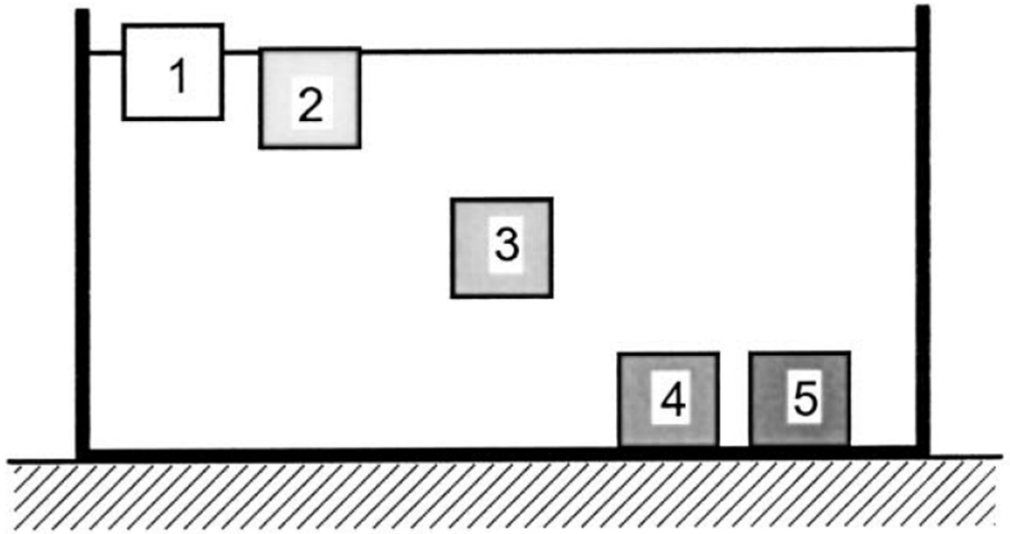


Explanation:

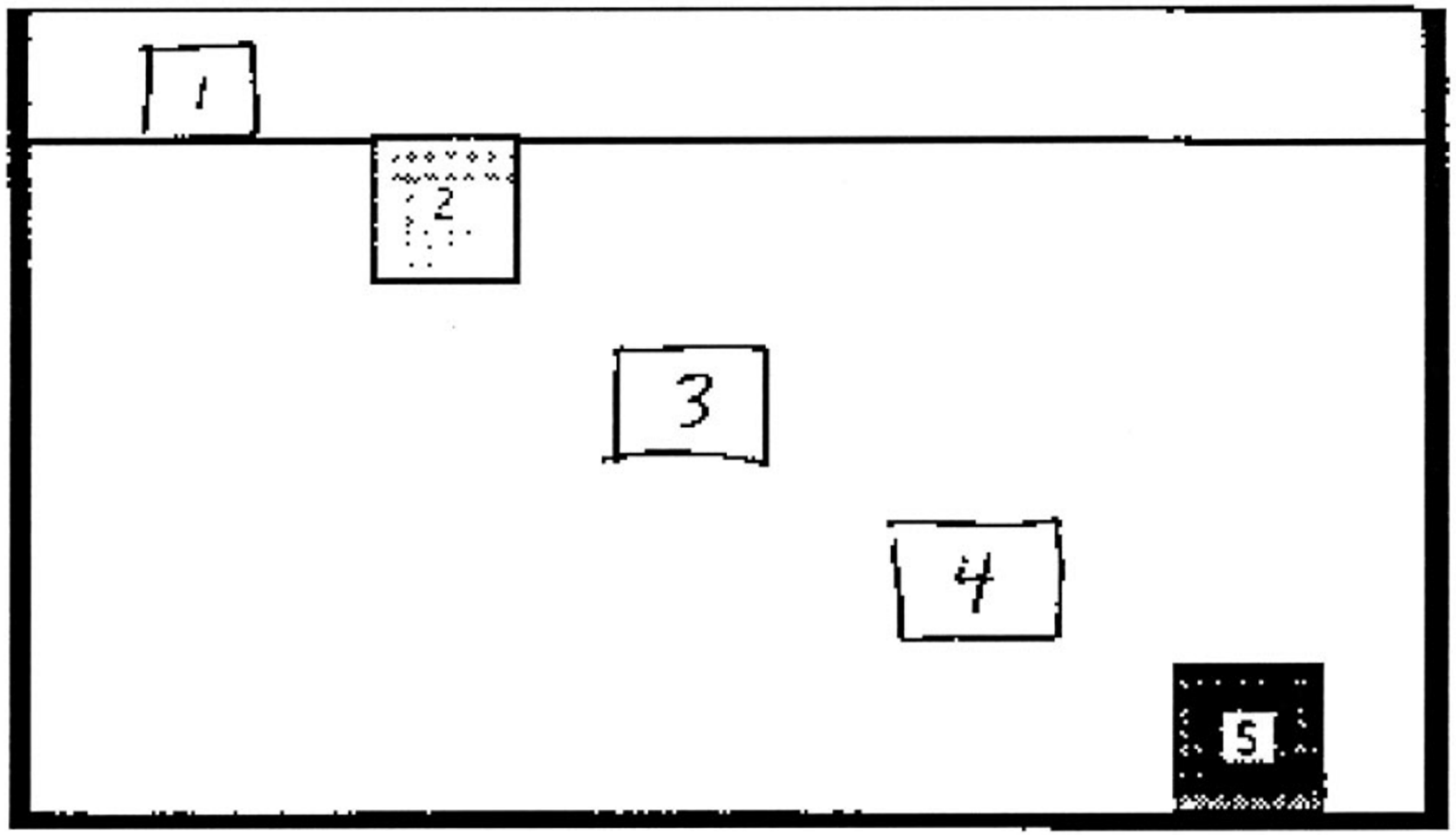
- The blocks all have the same volume, but different densities
- Blocks will either sink to bottom or float to top, depending on whether their density is larger or smaller than that of water
- A <u>maximum</u> of only one single block can be suspended in the water without sinking or floating (if its density is exactly equal to that of water)

Possible correct responses:





Common student incorrect response:



Students’ written explanations indicate conceptual difficulties

- Many students think incorrectly that the upward (buoyant) force [*Auftriebskraft*] on the submerged object is proportional to the object’s *mass*, instead of its volume
- Students often apply Newton’s laws incorrectly, not realizing that unless the upward buoyant force and the downward weight force are *exactly* equal, the object must float upward *or* sink down.

“Tutorials in Introductory Physics”:
Research-based instructional materials for classroom use

- Tutorials are printed worksheets, developed through research on students’ specific ideas and reasoning patterns
- Students work in groups of 3-4 on worksheets that pose a series of carefully sequenced questions
- Tutorial instructors ask additional questions intended to help students arrive at the answers themselves
- The overall goal is to guide students through the reasoning needed to construct and apply fundamental concept and principles

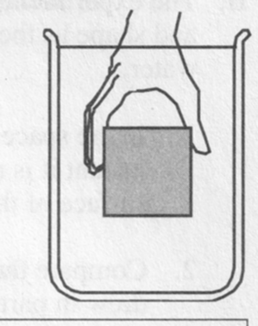
Tutorial in Introductory Physics at the University of Colorado

Tutorial on buoyancy, developed, assessed, and revised through research on students' reasoning.

Guides students through a careful analysis of the forces acting on a submerged object, and its resulting motion.

I. Buoyant force

A. A cubical block is observed to float in a beaker of water. The block is then held near the center of the beaker as shown and released.



1. Describe the motion of the block after it is released.

2. In the space provided, draw a free-body diagram for the block at the instant that it is released. Show the forces that the water exerts on each of the surfaces of the block separately.

   Free-body diagram for block at instant it is released

   Make sure the label for each force indicates:

   - the type of force,
   - the object on which the force is exerted, and
   - the object exerting the force.

3. Rank the magnitudes of the vertical forces in your free-body diagram. If you cannot completely rank the forces, explain why you cannot.

   Did you use the relationship between pressure and depth to compare the magnitudes of any of the vertical forces? If so, how?

   Did you use information about the motion of the block to compare the magnitudes of any of the vertical forces? If so, how?

4. In the box at right, draw an arrow to represent the vector sum of the forces exerted on the block by the surrounding water. How did you determine the direction?

   Sum of forces on block by water

Testing and revision of instructional materials

- After using preliminary version of tutorial, students' score on assessment questions is improved (55% correct compared to 35% correct); however:
- Further research indicates that students are confused about Archimedes' principle relating upward buoyant force to weight of "displaced" [*verdrängte*] water

  [„Der statische Auftrieb eines Körpers in einem Medium ist genauso groß wie die Gewichtskraft des vom Körper verdrängten Mediums."]

- Tutorial is revised with additional demonstration relating volume of displaced water to volume of the object
- Revised tutorial yields improved student scores (75% correct) on assessment problem

Iterative process of instructional materials development

1. Carry out research on students’ ideas about physical phenomena
2. Develop preliminary instructional materials based on the research
3. Assess effectiveness of instructional materials
4. Carry out further research to examine students’ thinking in greater depth

Pretest and post-test questions for assessment of student learning

Examples from research on Mechanics

Physics Education Group

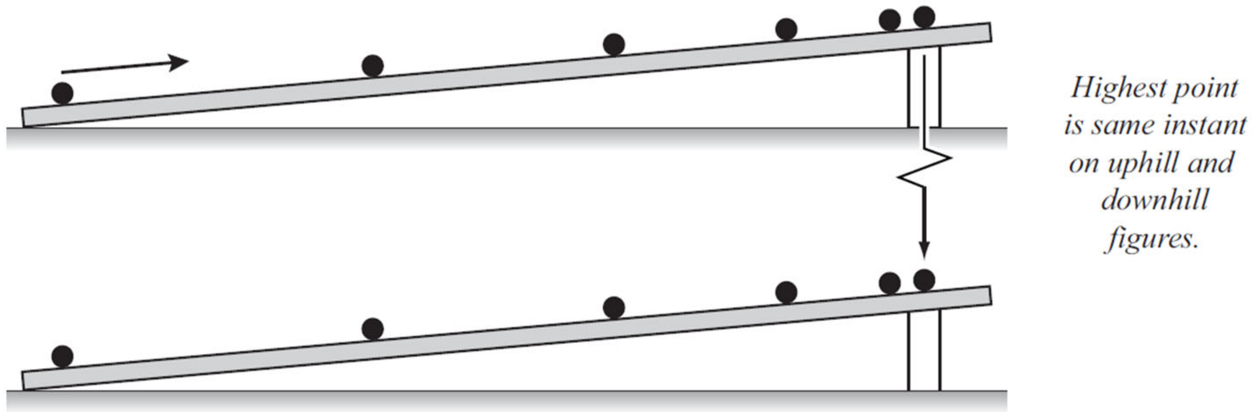
Research · Curriculum · Instruction

Physics Education Group
University of Washington
Seattle, WA

Assessment questions require students to explain their reasoning

The diagram below represents a strobe photograph of the motion of a ball as it rolls up and then down a track. (In a strobe photograph, the position of an object is shown at instants that are separated by equal time intervals.)

A. The arrow on the diagram represents the velocity of the ball at the first location. At each of the other locations shown, draw vectors to represent the *velocity* of the ball at those locations. If the velocity is zero at any of the locations, indicate that explicitly. Briefly explain why you drew the arrows as you did.



2	Ball on incline	1-d Kinematics	AJP **73** (10) 2005

A research-based approach to improving student understanding of the vector nature of kinematical concepts

Peter S. Shaffer and Lillian C. McDermott
Department of Physics, University of Washington, Seattle, Washington 98195-1560

(Received 6 April 2005; accepted 26 June 2005)

In this paper we describe a long-term, large-scale investigation of the ability of university students to treat velocity and acceleration as vectors in one and two dimensions. Some serious conceptual

Research results are published in professional journals

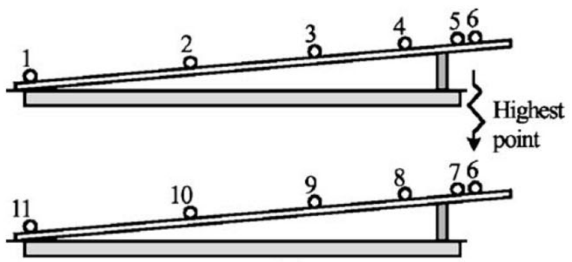


Fig. 3. Examples of pretests administered to large numbers of students. Students were asked to draw velocity and acceleration vectors at various points during each motion. (a) 1D pretest on ball moving up and down a ramp. (b) 2D pretest on object moving at constant speed along a closed, horizontal track. Some students were also asked about the case that the object speeds up from rest.

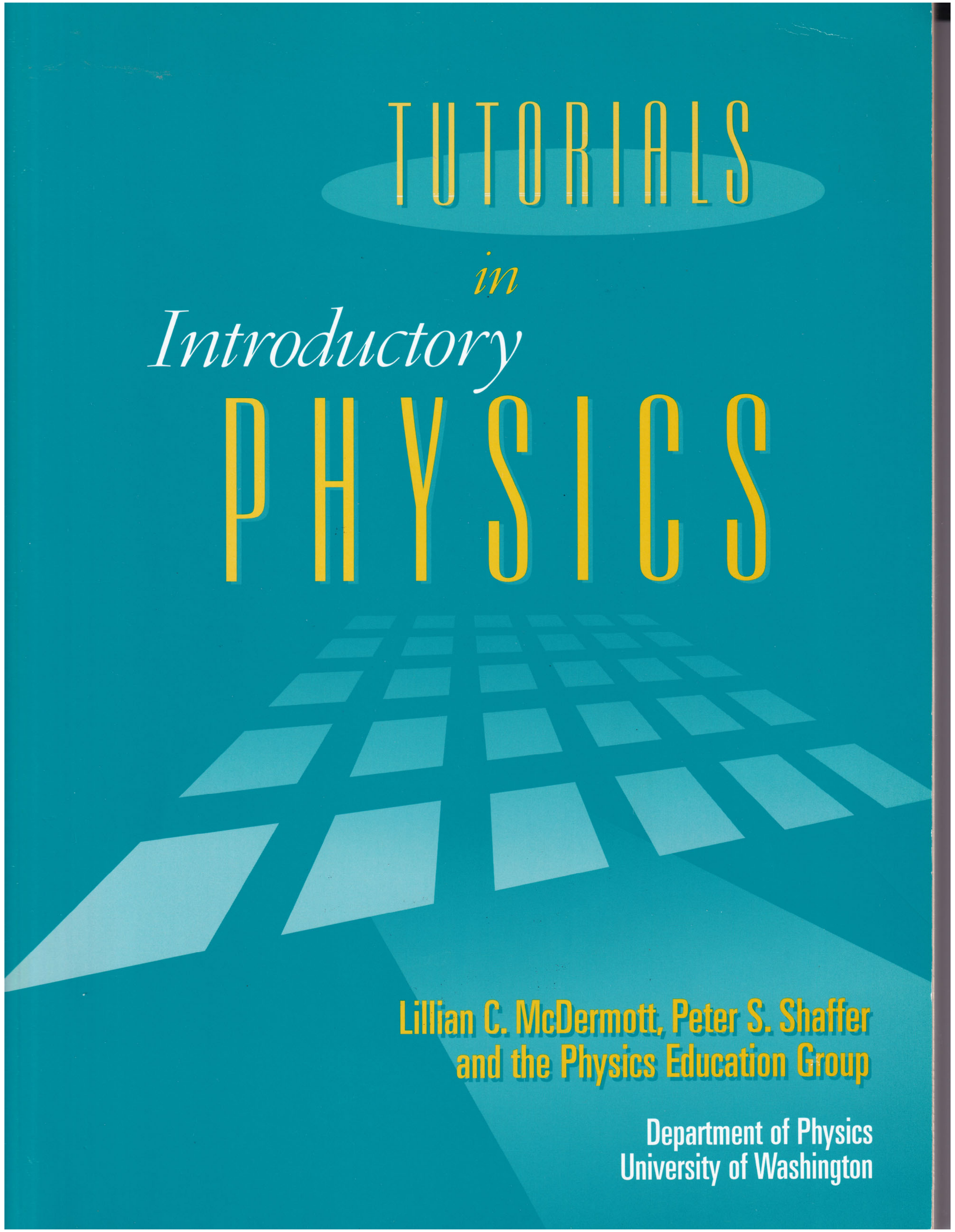
Table II. Results from 1D pretest on the ball on ramp [Fig. 3(a)] and 1D post-test on the motion of two blocks [Fig. 4(b)]. Not all students were asked about both the velocity and the acceleration.

	Pretest		Post-test
	Undergraduates[a]	TAs	Undergraduates[a]
Velocity	$N\sim715$	…	…
Correct (up along ramp, zero, down along ramp)	80%	…	…
Incorrect			
Nonzero vector drawn at point where $v=0$	15%	…	…
Acceleration	$N\sim20\,110$	$N\sim285$	$N\sim575$
Correct (down along ramp at all points)	20%	75%	75% (top only)
Incorrect[b]			
acceleration mimics velocity	20%	5%	…
acceleration straight down (at one or more points)	20%	10%	10%
acceleration zero at top	50%	15%	10%

[a]Includes results from most of the Ph.D. granting universities, which had very similar results. About 35% of the students [$N\sim500$] at Harvard University and in the UW honors section of calculus-based physics answered the question about acceleration correctly. These data are not included.
[b]Categories not mutually exclusive.

Iterative process of instructional materials development

1. Carry out research on students’ ideas about physical phenomena
2. Develop preliminary instructional materials based on the research
3. Assess effectiveness of instructional materials
4. Carry out further research to examine students’ thinking in greater depth
5. Develop revised and updated instructional materials to reflect additional research
6. Further assess the effectiveness of revised instructional materials
7. Publish materials; disseminate to other instructors and schools


TUTORIALS
in
Introductory
PHYSICS
Lillian C. McDermott, Peter S. Shaffer
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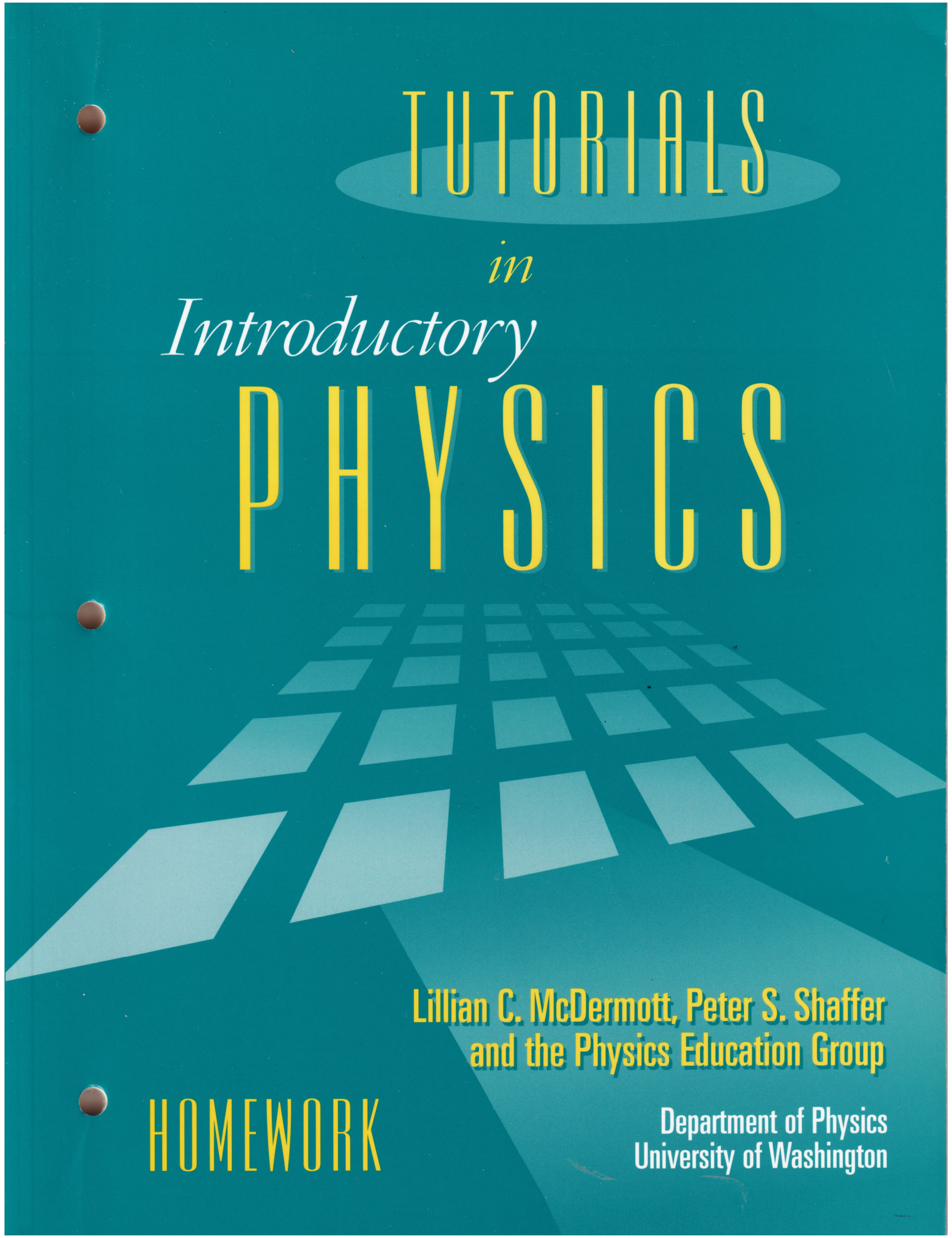
Department of Physics
University of Washington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Introductory
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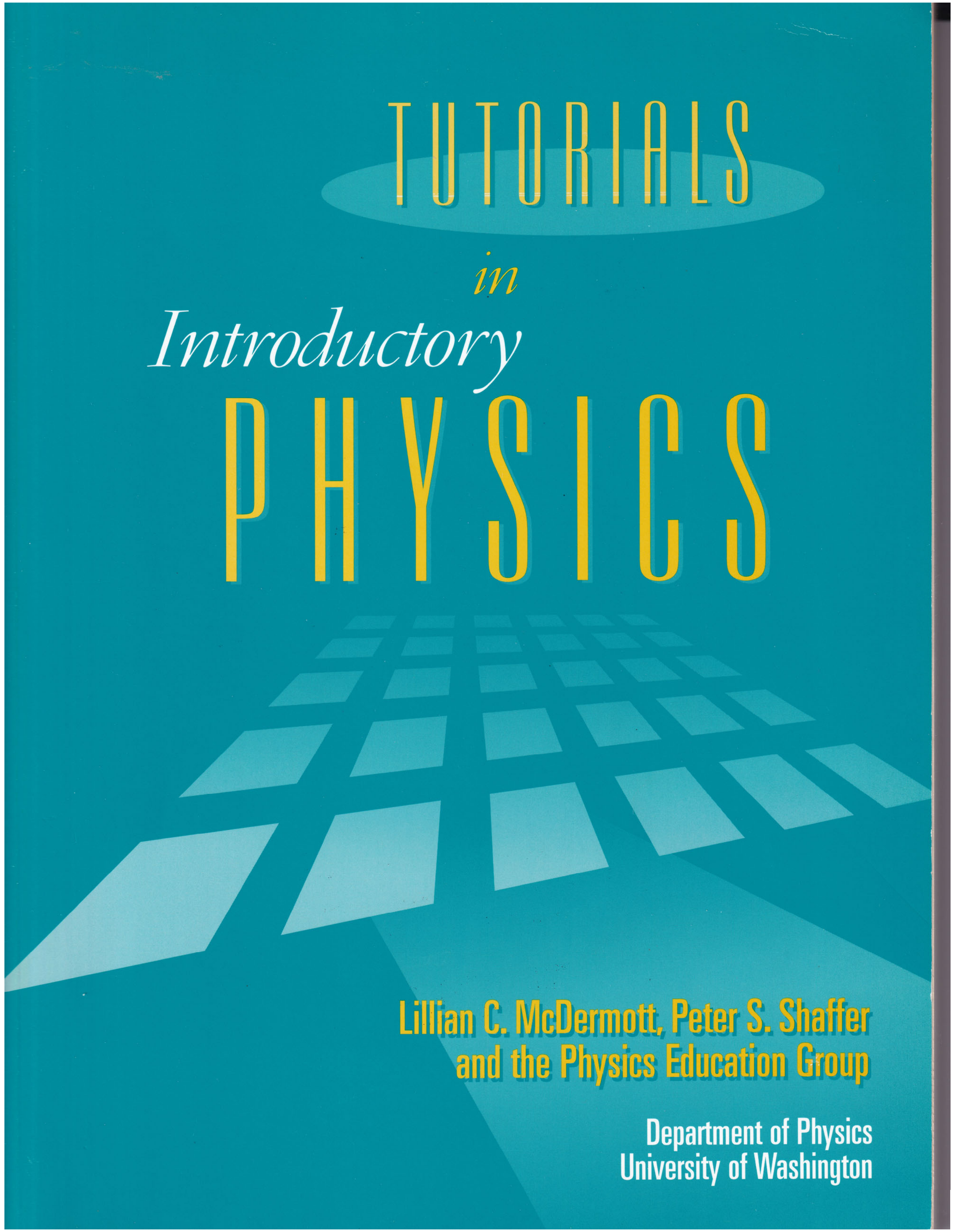
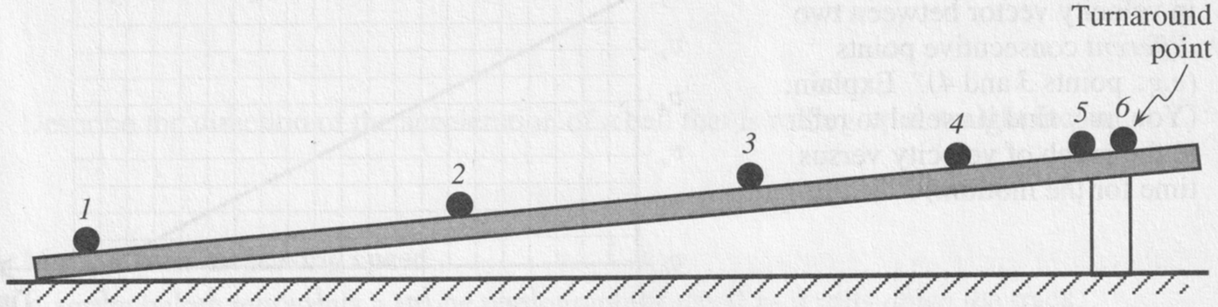
and the Physics Education Group
HOMEWORK
Department of Physics
University of Washington



ACCELERATION IN ONE DIMENSION

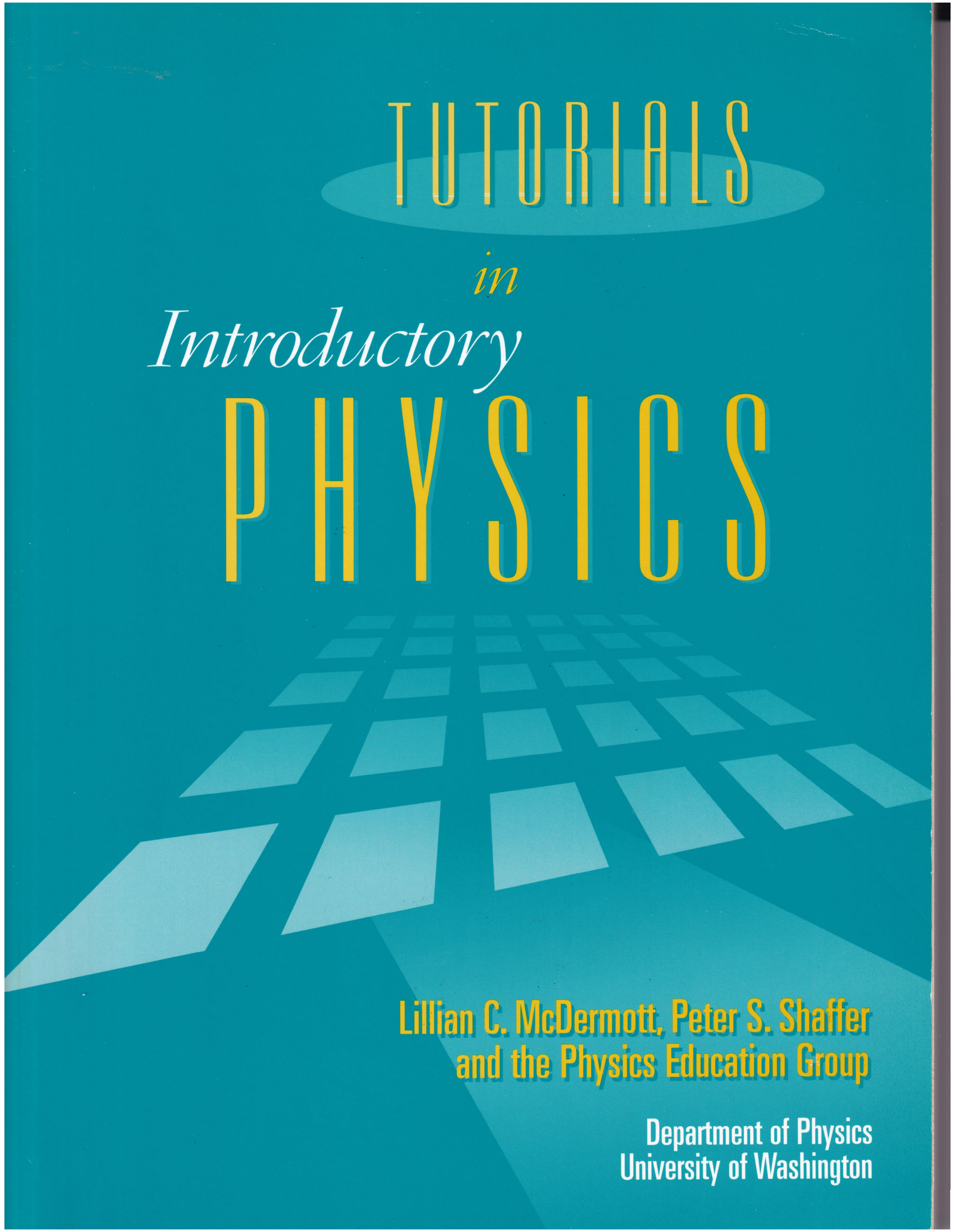
I. Motion with decreasing speed

The diagram below represents a strobe photograph of a ball as it rolls *up* a track. (In a strobe photograph, the position of an object is shown at instants separated by *equal time intervals*.)



A. Draw vectors on your diagram that represent the instantaneous velocity of the ball at each of the labeled locations. If the velocity is zero at any point, indicate that explicitly. Explain why you drew the vectors as you did.

We will call diagrams like the one you drew above *velocity diagrams*. Unless otherwise specified, a velocity diagram shows both the location and the velocity of an object at instants in time that are separated by equal time intervals.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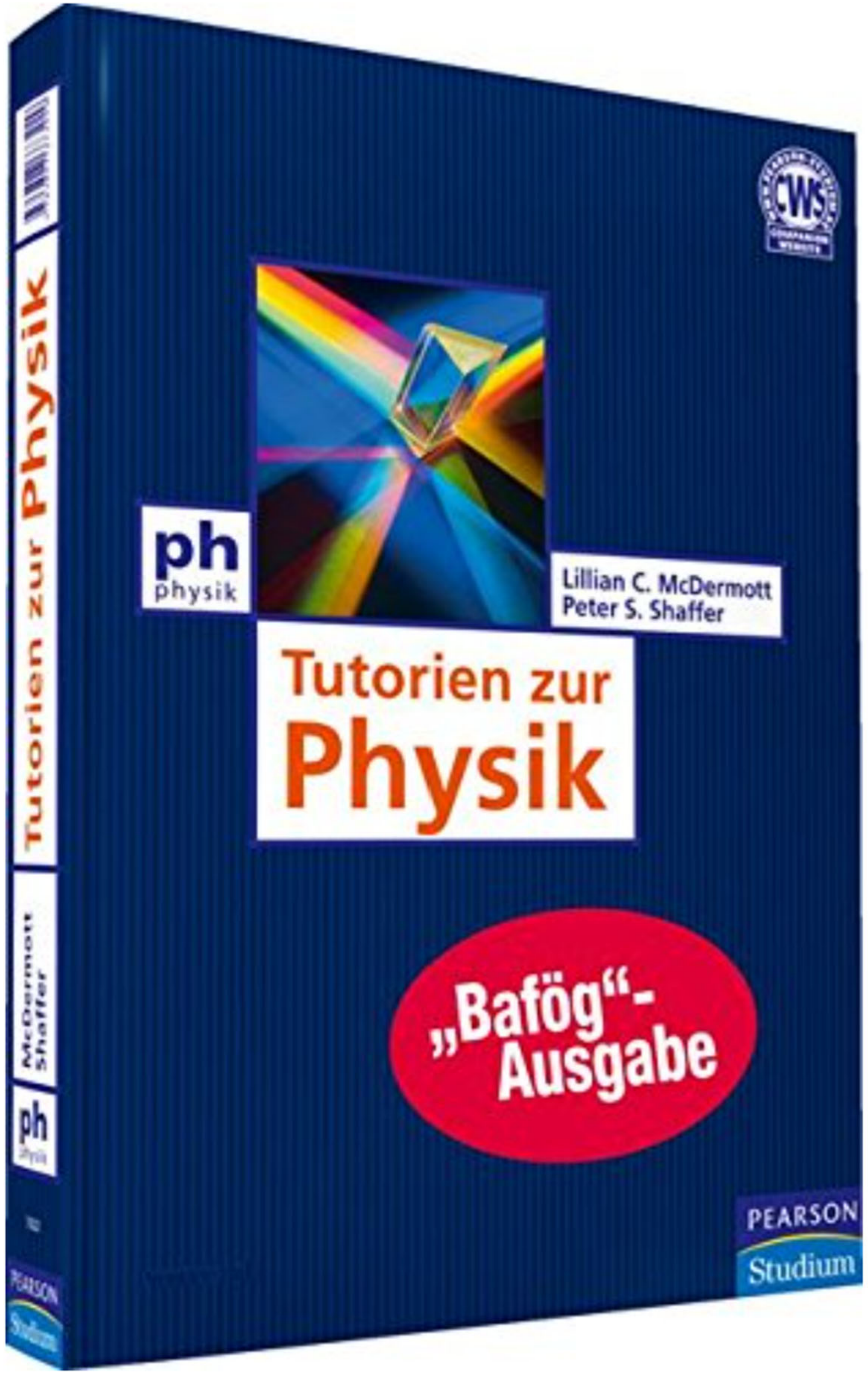
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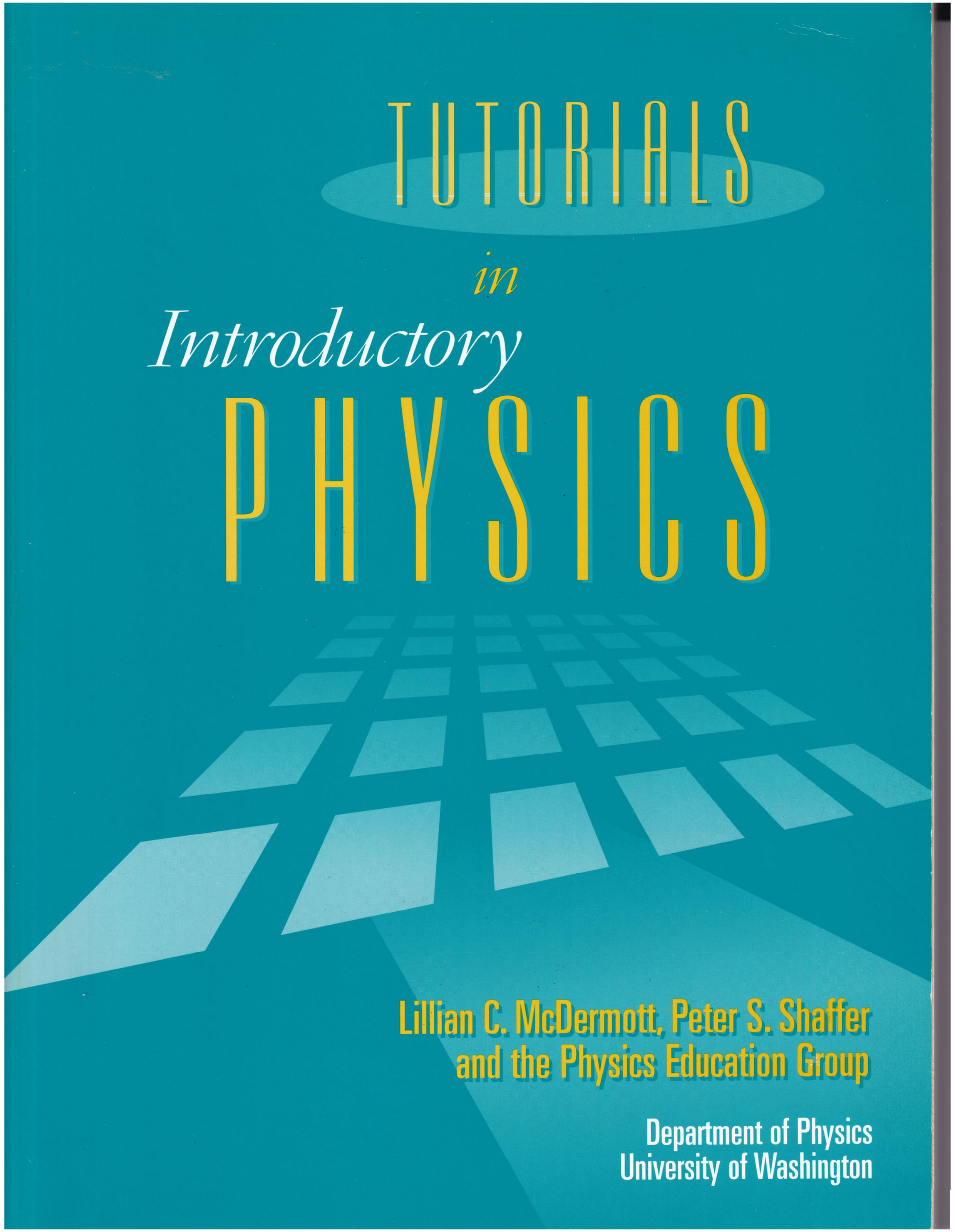
McDermott
Shaffer
ph
physik
Lillian C. McDermott
Peter S. Shaffer
Tutorien zur
Physik
„Bafög“-
Ausgabe
PEARSON
Studium

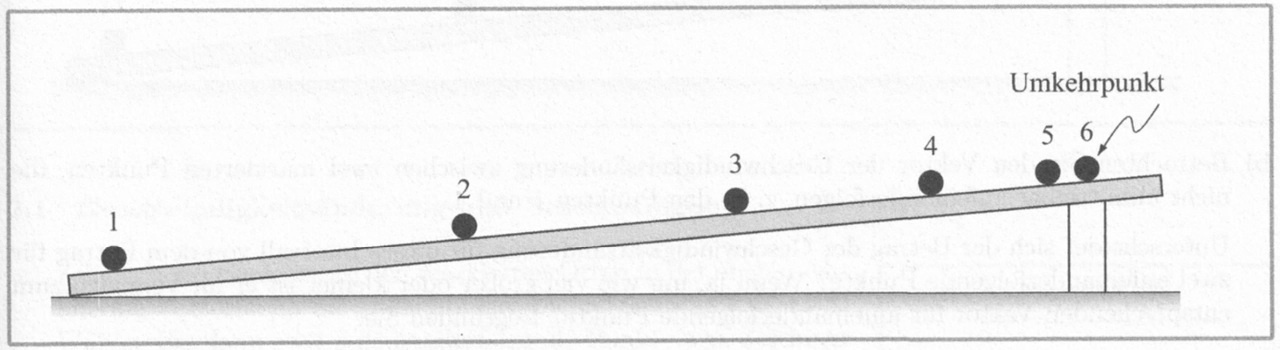

TUTORIALS
in
Introductory
PHYSICS
Lillian C. McDermott, Peter S. Shaffer
and the Physics Education Group
Department of Physics
University of Washington


LEHRBUCH
Christian Kautz
Andrea Brose
Norbert Hoffmann
Tutorien zur
Technischen Mechanik
Arbeitsmaterialien für das Lehren und
Lernen in den Ingenieurwissenschaften
Springer Vieweg

Im vorliegenden Arbeitsblatt beginnen wir mit der Betrachtung von Bewegungen, zunächst für Situationen, in denen die Bewegung entlang einer geraden Linie verläuft. Hierbei wird noch nicht nach einer Erklärung für den Verlauf der Bewegung gesucht, sondern es werden nur Begriffe zur Beschreibung von Bewegungen festgelegt und verwendet.

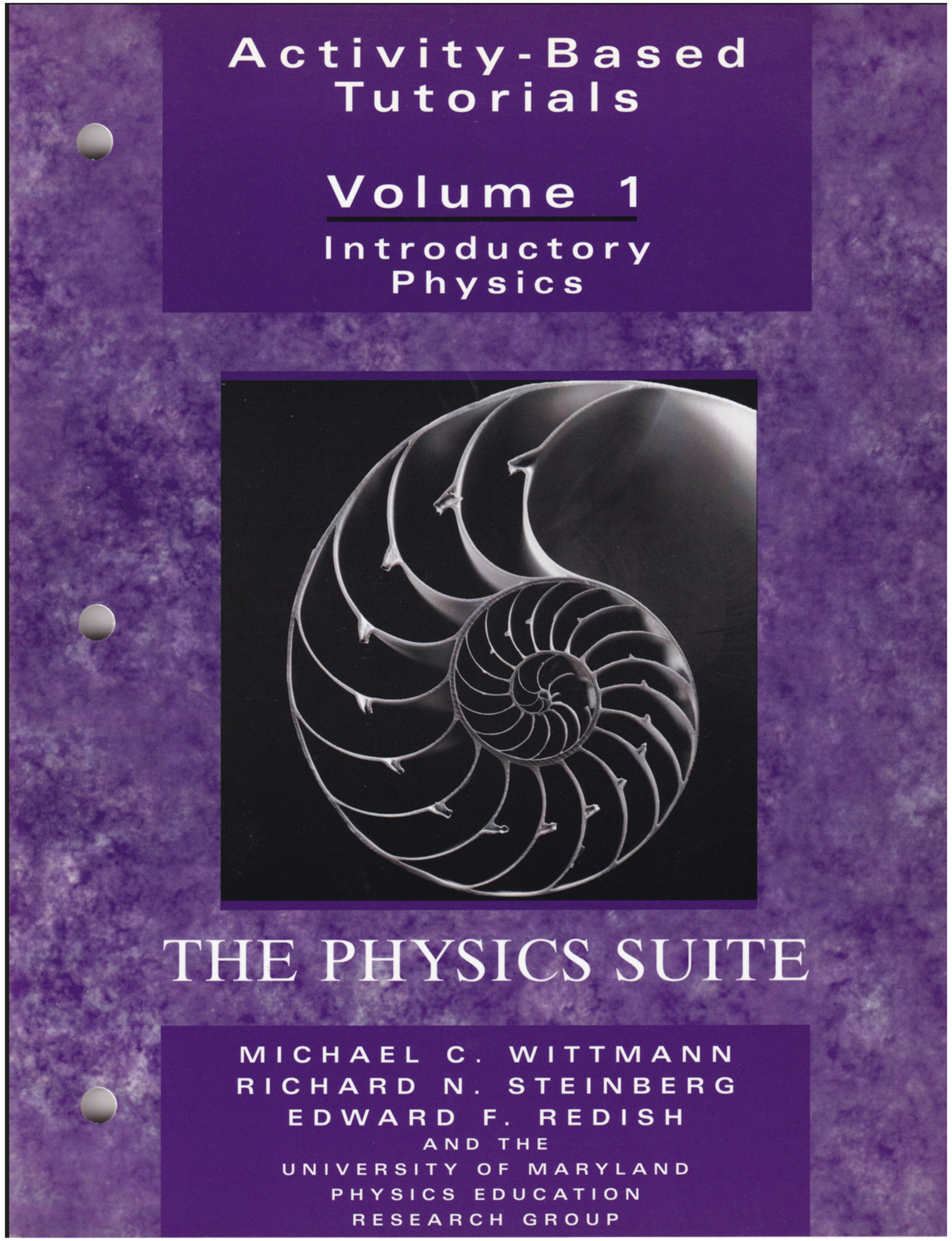
1 Bewegung mit abnehmendem Geschwindigkeitsbetrag

Die folgende Abbildung zeigt die Stroboskopaufnahme einer Kugel, die auf einer geneigten Schiene aufwärts rollt. (In einer Stroboskopaufnahme ist der Aufenthaltsort eines Gegenstandes nach jeweils gleichen Zeitintervallen zu sehen.)

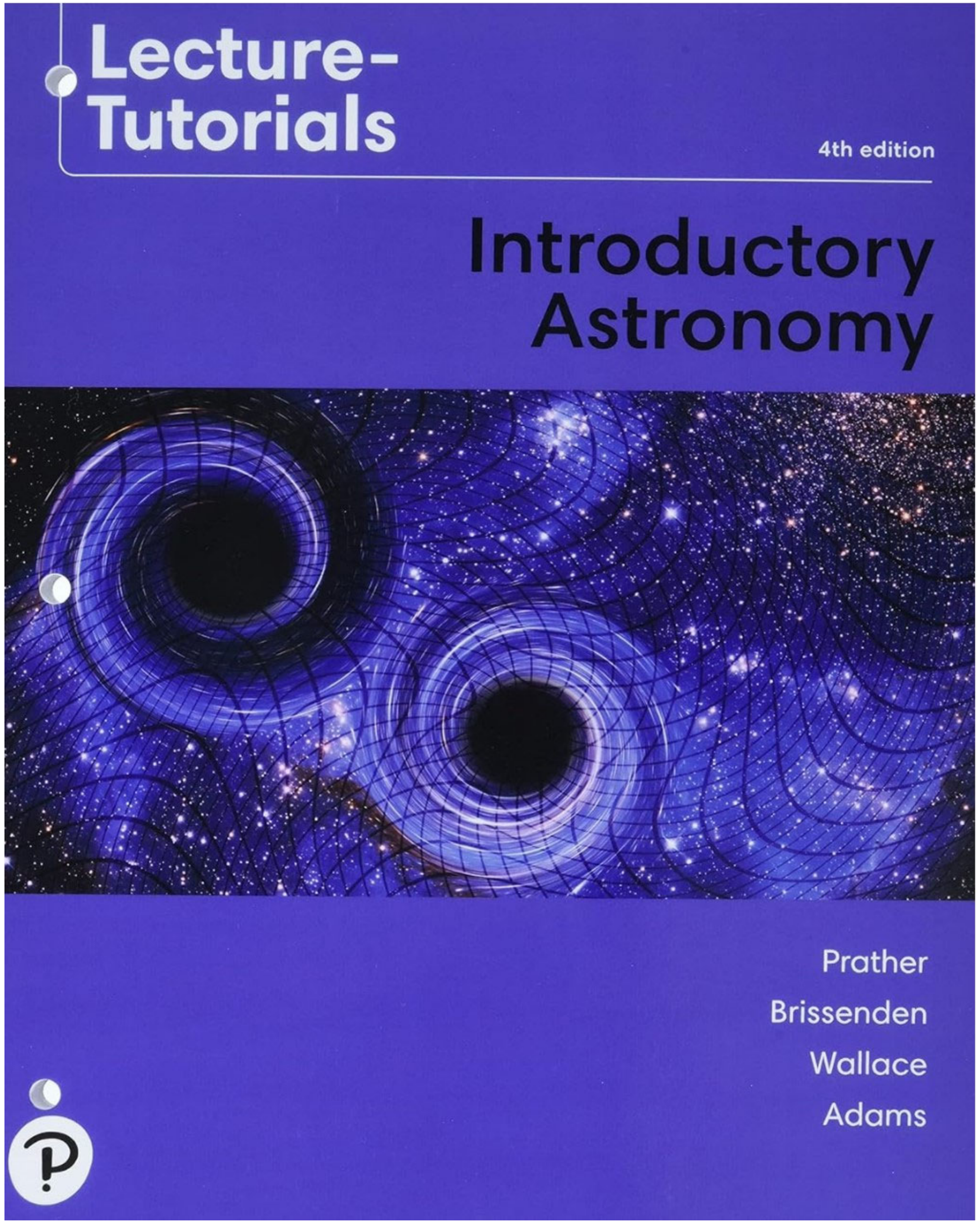


1.1 Geschwindigkeit und Geschwindigkeitsänderung

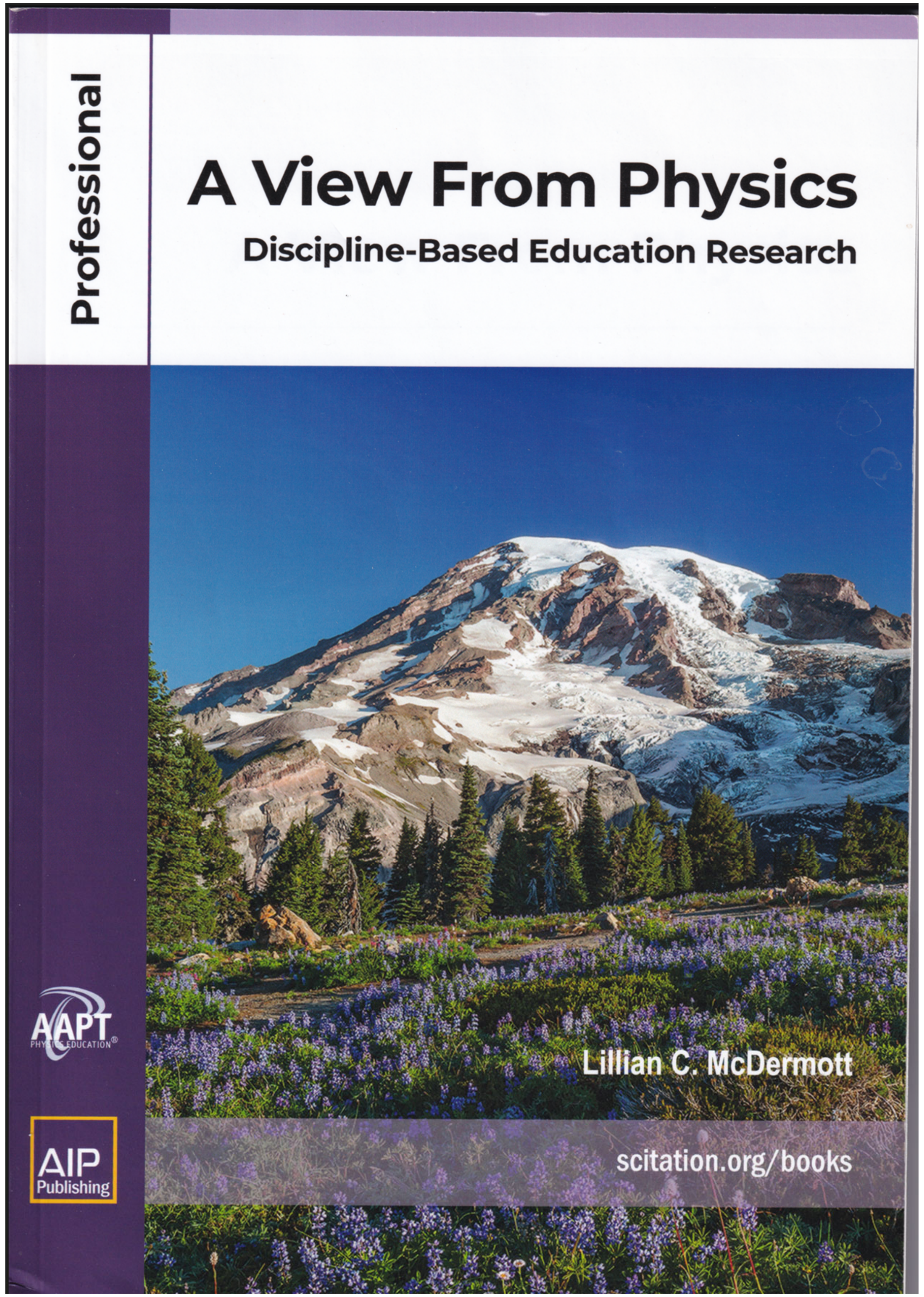
a) Zeichnen Sie an den markierten Orten in der Abbildung Vektoren für die Momentangeschwindigkeit der Kugel ein. Falls die Geschwindigkeit an einem der Punkte gleich null ist, geben Sie dies ausdrücklich an. Begründen Sie, warum Sie die Vektoren in dieser Weise gezeichnet haben.



Research-based tutorials developed by the University of Maryland

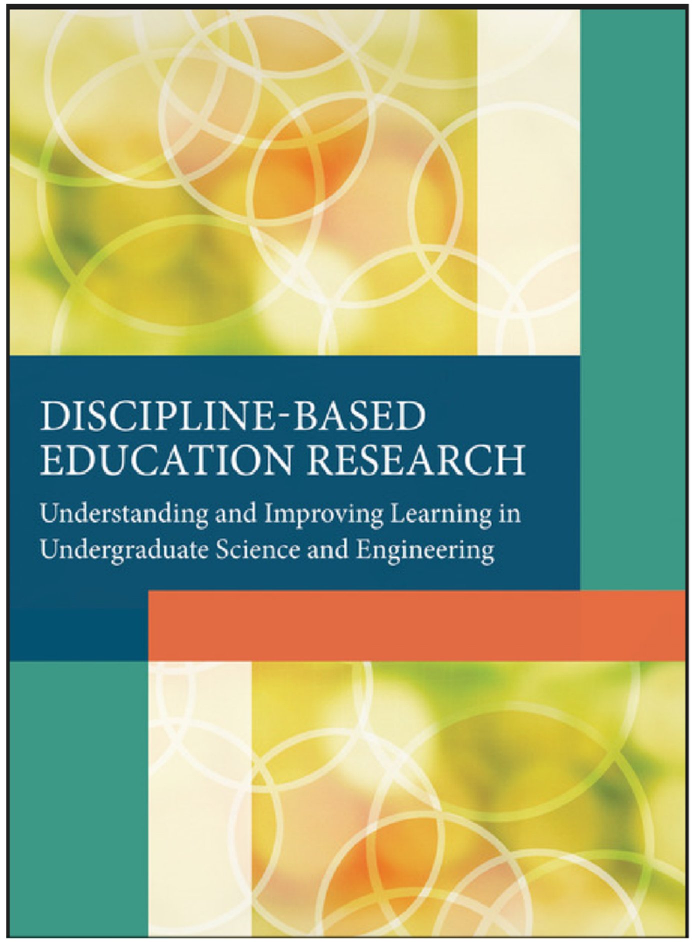


Research-based tutorials in Astronomy, developed by multi-institutional collaboration



In her final work—the 2021 book “A View From Physics”-- McDermott explained how the success of research in physics education has formed a model followed by many other disciplines such as chemistry, astronomy, biology, and geosciences.

The ongoing research work in university-level science education in the United States has been documented in detail by the U.S. National Research Council:



Other models of research-based active learning in STEM

- The research model developed and implemented by Lillian McDermott at the University of Washington has been extremely successful. However, it is relatively slow and resource-intensive, requiring long-term collaboration of research teams of professors, post-doctoral researchers, and graduate students. Many other models have been employed with success over the past 50 years.

- A central feature of all research-based work in STEM education is that there must be tool to investigate and assess students' thinking. So-called "diagnostic assessment instruments" of all types have been developed.

Force Concept Inventory

By David Hestenes, Malcolm Wells, and Gregg Swackhamer

Every student begins physics with a well-established system of commonsense beliefs about how the physical world works derived from years of personal experience. Over the last decade, physics education research has established that these beliefs play a dominant role in introductory physics. Instruction that does not take them into account is almost totally ineffective, at least for the majority of students.

Specifically, it has been established that[1] (1) commonsense beliefs about motion and force are incompatible with Newtonian concepts in most respects, (2) conventional physics instruction produces little change in these beliefs, and (3) this result is independent of the instructor and the mode of instruction. The implications could not be more serious. Since the students have evidently not learned the most basic Newtonian concepts, they must have failed to comprehend most of the material in the course. They have been forced to cope with the subject by rote memorization of isolated fragments and by carrying out meaningless tasks. No wonder so many are repelled! The few who are successful have become so by their own devices, the course and the teacher having supplied only the opportunity and perhaps inspiration.

The authors, David Hestenes, Malcolm Wells, and Gregg Swackhamer are trying to make a point!

David Hestenes *is a professor of theoretical physics at Arizona State University. He has been active in physics education research for more than a decade. He also has current research in relativistic electron theory and neural network modeling of the brain (Department of Physics and Astronomy, Arizona State University, Tempe, AZ 85287).*

Malcolm Wells *has been a high-school physics teacher for three decades. In 1986 he received the Presidential Award for Excellence in Science Education. In 1987 he completed a doctorate in physics education research. He is currently collaborating with Hestenes on an NSF grant for educational research and teacher enhancement (Marcos de Niza High School, Tempe, AZ 85283).*

Gregg Swackhamer *has taught high-school physics for 13 years. He has B.S. and M.A.T. degrees from Indiana University. He is currently teaching physics at Glenbrook North High School (Northbrook, IL 60062) from which he took sabbatical leave in 1989–90 to study at Arizona State University and work on this project.*

One of the most widely used and influential assessments of physics concept knowledge has been the "Force Concept Inventory" (FCI), published in 1992

The FCI was based on research on students' ideas by Halloun and Hestenes (1985):

The initial knowledge state of college physics students

Ibrahim Abou Halloun[a] and David Hestenes
Department of Physics, Arizona State University, Tempe, Arizona 85287

(Received 1 August 1984; accepted for publication 28 January 1985)

An instrument to assess the basic knowledge state of students taking a first course in physics has been designed and validated. Measurements with the instrument show that the student's initial qualitative, common sense beliefs about motion and causes has a large effect on performance in physics, but conventional instruction induces only a small change in those beliefs.

Common sense concepts about motion

Ibrahim Abou Halloun[a] and David Hestenes
Department of Physics, Arizona State University, Tempe, Arizona 85287

(Received 1 August 1984; accepted for publication 28 January 1985)

Common sense beliefs of college students about motion and its causes are surveyed and analyzed. A taxonomy of common sense concepts which conflict with Newtonian theory is developed as a guide to instruction.

The current version contains 30 “multiple-choice” questions [*Mehrfachauswahl*]

Force Concept Inventory

Erste Veröffentlichung in *The Physics Teacher,* März 1992
von
David Hestenes, Malcolm Wells und Gregg Swackhamer

Überarbeitung der englischen Fassung im August 1995
von
Ibrahim Halloun, Richard Hake und Eugene Mosca

Deutsche Übersetzung
von
Christian Kautz

basierend auf einer Übersetzung der ersten Fassung
von
H. Schecker und J. Gerdes

17. Ein Fahrstuhl wird in einem Fahrstuhlschacht von einem Stahlseil mit konstanter Geschwindigkeit nach oben gezogen (vgl. Skizze). Alle Reibungskräfte sind zu vernachlässigen. In diesem Fall gilt für die Kräfte, die *auf den Fahrstuhl* ausgeübt werden:

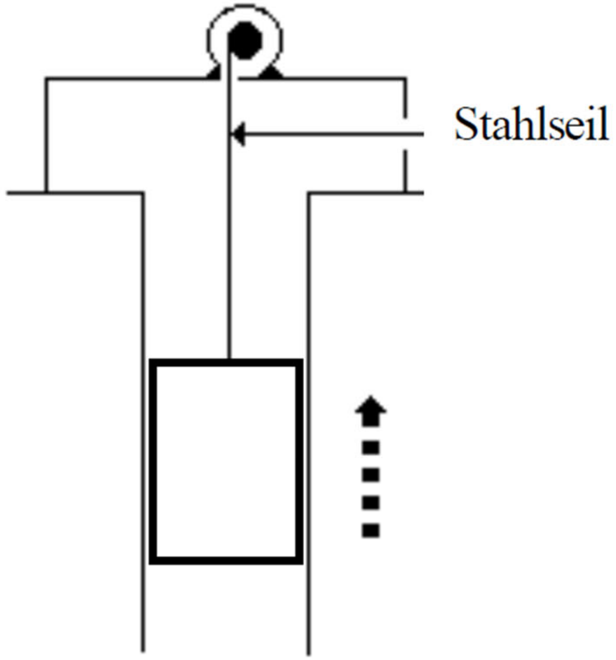
(A) Die nach oben gerichtete Kraft durch das Seil ist größer als die nach unten gerichtete Schwerkraft.

✓ (B) Die nach oben gerichtete Kraft durch das Seil ist genau so groß wie die nach unten gerichtete Schwerkraft.

(C) Die nach oben gerichtete Kraft durch das Seil ist geringer als die nach unten gerichtete Schwerkraft.

(D) Die nach oben gerichtete Kraft durch das Seil ist größer als die Summe aus der nach unten gerichteten Schwerkraft und der nach unten gerichteten Kraft des Luftdrucks.

(E) Keine der obigen Antworten ist richtig. (Der Fahrstuhl bewegt sich nach oben, weil das Seil aufgewickelt wird, aber nicht deshalb, weil das Seil eine Kraft auf den Fahrstuhl ausübt).



Fahrstuhl bewegt sich mit
konstanter Geschwindigkeit nach oben

17. Ein Fahrstuhl wird in einem Fahrstuhlschacht von einem Stahlseil $\boxed{\text{mit konstanter Geschwindigkeit}}$ nach oben gezogen (vgl. Skizze). Alle Reibungskräfte sind zu vernachlässigen. In diesem Fall gilt für die Kräfte, die *auf den Fahrstuhl* ausgeübt werden:

X

(A) Die nach oben gerichtete Kraft durch das Seil ist größer als die nach unten gerichtete Schwerkraft.

(B) Die nach oben gerichtete Kraft durch das Seil ist genau so groß wie die nach unten gerichtete Schwerkraft.

(C) Die nach oben gerichtete Kraft durch das Seil ist geringer als die nach unten gerichtete Schwerkraft.

(D) Die nach oben gerichtete Kraft durch das Seil ist größer als die Summe aus der nach unten gerichteten Schwerkraft und der nach unten gerichteten Kraft des Luftdrucks.

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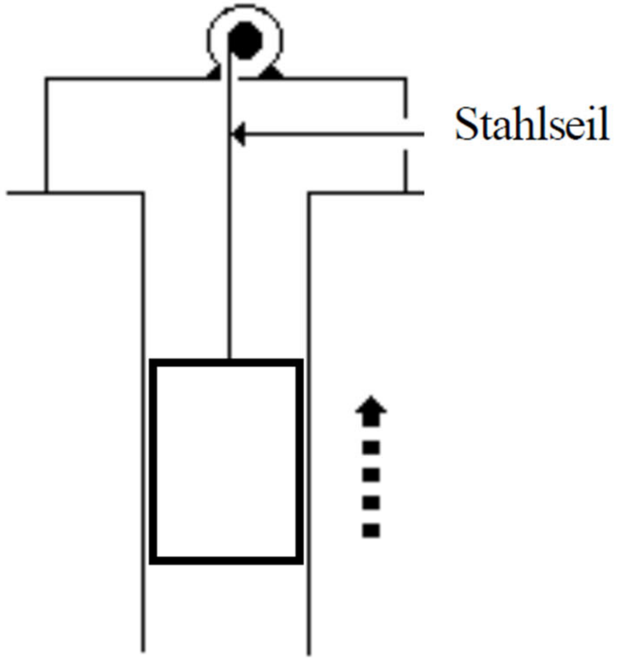


Fahrstuhl bewegt sich mit konstanter Geschwindigkeit nach oben

Am. J. Phys. **66** (1), January 1998

Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses

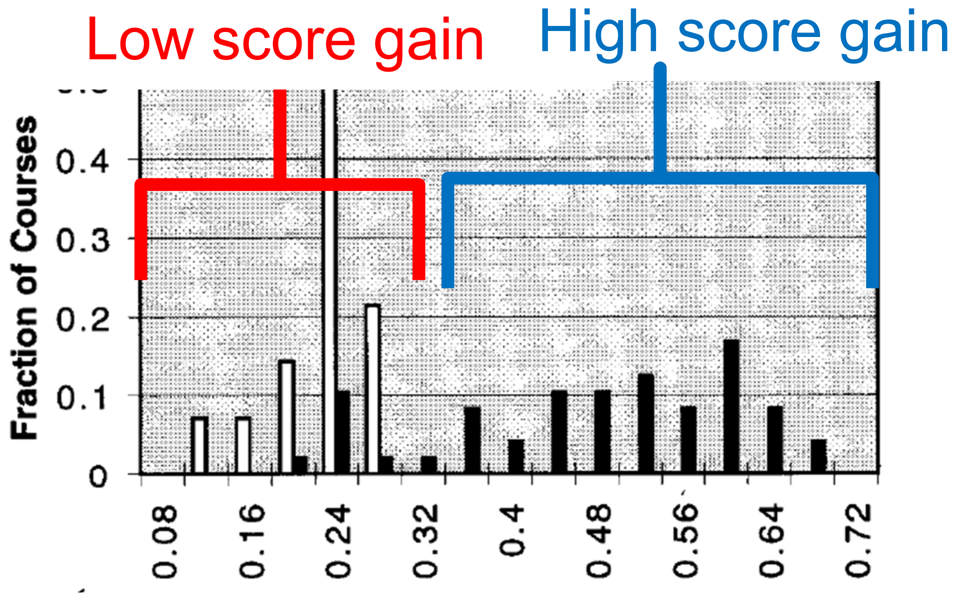
Richard R. Hake[a)]
Department of Physics, Indiana University, Bloomington, Indiana 47405

(Received 6 May 1996; accepted 4 May 1997)

A survey of pre/post-test data using the Halloun–Hestenes Mechanics Diagnostic test or more recent Force Concept Inventory is reported for 62 introductory physics courses enrolling a total number of

Traditional lecture-based courses

Courses using research-based active-learning instruction



Fractional score gain on Force Concept Inventory

Fig. 2. Histogram of the average normalized gain $\langle g \rangle$: white bars show the *fraction* of 14 traditional courses ($N=2084$), and black bars show the *fraction* of 48 interactive engagement courses ($N=4458$), both within bins of width $\delta\langle g \rangle = 0.04$ centered on the $\langle g \rangle$ values shown.

Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses

Richard R. Hake[a)]
Department of Physics, Indiana University, Bloomington, Indiana 47405

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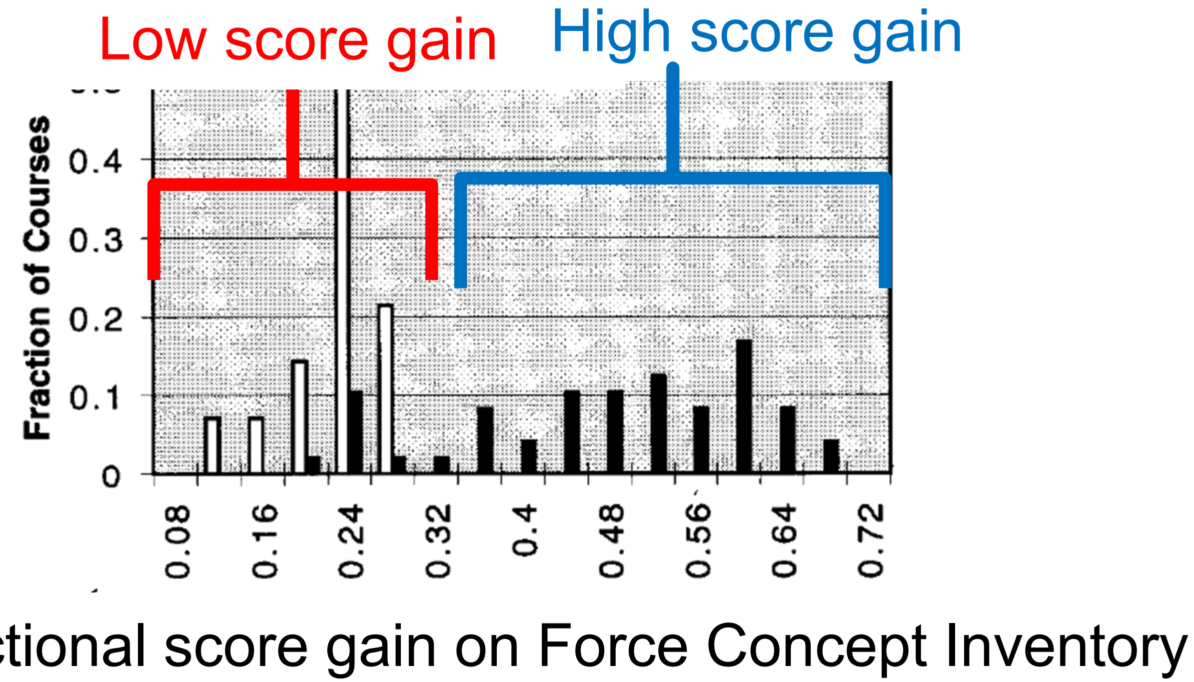

Much higher gains on assessment test for courses that used active-learning instruction

Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses

Richard R. Hake[a]
Department of Physics, Indiana University, Bloomington, Indiana 47405

(Received 6 May 1996; accepted 4 May 1997)

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- ☐ Beliefs / Attitudes
- ☐ Teaching
- ☐ Department Climate

Format

Any

- ☐ Pre/post ?
- ☐ Multiple-choice
- ☐ Multiple-response ?
- ☐ Agree/disagree ?

108 Research-Based Assessments

Quick Filter

Sort by: Subject

Content knowledge

Force Concept Inventory (FCI)
Mechanics Content knowledge (forces, kinematics)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
30 min

Force and Motion Conceptual Evaluation (FMCE)
Mechanics Content knowledge (kinematics, forces, energy, graphing)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
35 min

Feedback

Content knowledge

Force Concept Inventory (FCI)
Mechanics Content knowledge (forces, kinematics)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
30 min

Force and Motion Conceptual Evaluation (FMCE)
Mechanics Content knowledge (kinematics, forces, energy, graphing)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
35 min

Test of Understanding Graphs in Kinematics (TUG-K)
Mechanics Content knowledge (kinematics, graphing)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
45 min

Energy Concept Assessment (ECA)
Mechanics Content knowledge (energy principle, forms of energy, work and heat, absorption/emission spectrum, specifying appropriate systems)
Levels: Intro college
Formats: Pre/post, Multiple-choice
30-60 min

Energy and Momentum Conceptual Survey (EMCS)
Mechanics Content knowledge (energy, momentum)
Levels: Intro college
Formats: Pre/post, Multiple-choice
50 min

Colorado Classical Mechanics/Math Methods Instrument (CCMI)
Mechanics Content knowledge (ordinary differential equations, Taylor series, potential energy, simple harmonic motion, Newton's laws)
Levels: Upper-level, Intermediate
Formats: Pre/post, Short answer
Pre: 20 min; Post: 50 min

Rotational Kinematics Inventory (RKI)
Mechanics Content knowledge (Part 1: rotational kinematics of a particle, Part 2: rotational kinematics of a particle in rectilinear motion, Part 3: rotational kinematics of a rigid body about a fixed axis)
Levels: Intro college
Formats: Multiple-choice
50-60 min

Flight Physics Concept Inventory (FliP-CoIn)
Mechanics Content knowledge (Flight physics concepts, drag, stall, angle of attack, center of mass, lift, streamline properties)
Levels: Upper-level, Intermediate, Intro college
Formats: Multiple-choice
25 min

Half-length Force Concept Inventory (HFCI)
Mechanics Content knowledge (forces, kinematics)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
15 min

Inventory of Basic Conceptions - Mechanics (IBCM)
Mechanics Content knowledge (forces, kinematics)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
30 min

Next Gen Physical Science Diagnostic (NGPSD)
Mechanics Content knowledge (magnetism, static electricity, energy, forces, waves and sound, light)
Levels: Intro college
Formats: Pre/post, Multiple-choice
5 (each unit) min

Rotational and Rolling Motion Conceptual Survey (RRMCS)

Mechanics Baseline Test (MBT)
Mechanics Content knowledge (kinematics, forces, momentum, energy)
Levels: Intro college, High school
Formats: Multiple-choice
45 min

Representational Variant of the Force Concept Inventory (R-FCI)
Mechanics Content knowledge (kinematics, forces, graphing, multiple representations)
Levels: High school
Formats: Pre/post, Multiple-choice
30 min

Force, Velocity, and Acceleration Test (FVA)
Mechanics Content knowledge (forces, velocity, acceleration)
Levels: Intro college
Formats: Pre/post, Multiple-choice, Multiple-response
20 min

Density Survey (DS)
Mechanics Content knowledge (density)
Levels: Intro college, High school, Middle school
Formats: Multiple-choice
15 min

Brief Electricity and Magnetism Assessment (BEMA)
Electricity / Magnetism Content knowledge (circuits, electrostatics, magnetic fields and forces)
Levels: Upper-level, Intro college
Formats: Pre/post, Multiple-choice
45 min

Colorado Upper Division Electrostatics Diagnostic - Coupled Multiple Response (CUE-CMR)
Electricity / Magnetism Content knowledge (electrostatics, magnetostatics, choosing a problem-solving method)
Levels: Upper-level
Formats: Pre/post, Multiple-choice, Multiple-response
Pre: 20 min; Post: 50 min

Colorado Upper Division Electrostatics Diagnostic - Free Response (CUE-FR)
Electricity / Magnetism Content knowledge (electrostatics, magnetostatics, choosing a problem-solving method)
Levels: Upper-level
Formats: Pre/post, Short answer
Pre: 20 min; Post: 50 min

Determining and Interpreting Resistive Electric Circuit Concepts Test (DIRECT)
Electricity / Magnetism Content knowledge (DC circuits)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
30 min

Conceptual Survey of Electricity and Magnetism (CSEM)
Electricity / Magnetism Content knowledge (electrostatics, magnetic fields and forces, Faraday's law)
Levels: Intro college
Formats: Pre/post, Multiple-choice
50 min

Diagnostic Exam for Introductory, Undergraduate Electricity and Magnetism (DEEM)
Electricity / Magnetism Content knowledge (electric fields and force, magnetic fields and forces, electrostatic potential, Maxwell's equations, induced currents)
Levels: Intro college
Formats: Pre/post, Multiple-choice
50 min

Magnetism Conceptual Survey (MCS)
Electricity / Magnetism Content knowledge (magnetic fields and forces, Faraday's law)
Levels: Intro college, High school
50 min

Feedback

Rate and Potential Test (RAPT)
Electricity / Magnetism Content knowledge (electric potential, rate of change)
Levels: Intro college
Formats: Multiple-choice
30 min

Inventory of Basic Conceptions - DC Circuits (IBCDC)
Electricity / Magnetism Content knowledge (DC circuits)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
30 min

Colorado UppeR-division ElectrodyNamics Test (CURrENT)
Electricity / Magnetism Content knowledge (vector calculus, complex exponentials, time-dependent Maxwell equations, Ohm's law, conservation of charge and energy, electromagnetic plane wave, transmission & reflection)
Levels: Upper-level
Formats: Pre/post, Short answer
Pre: 15 min, Post: 50 min

Symmetry and Gauss's Law Conceptual Evaluation (SGCE)
Electricity / Magnetism Content knowledge (symmetry, electric field, electric flux)
Levels: Graduate, Upper-level, Intermediate, Intro college
Formats: Pre/post, Multiple-choice
50 min

Electric Circuits Conceptual Evaluation (ECCE)
Electricity / Magnetism Content knowledge (DC and AC circuits)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice, Short answer
60 min

Electricity and Magnetism Conceptual Assessment (EMCA)
Electricity / Magnetism Content knowledge (electrostatics, electric fields and force, circuits, magnetism, induction)
Levels: Intro college
Formats: Pre/post, Multiple-choice
45 min

Electromagnetics Concept Inventory (EMCI)
Electricity / Magnetism Content knowledge (Electromagnetic fields, electromagnetic waves)
Levels: Upper-level
Formats: Multiple-choice

Mechanical Wave Conceptual Survey (MWCS)
Waves / Optics Content knowledge (mechanical waves, wave propagation, wave superposition, wave reflection, standing waves)
Levels: Intermediate, Intro college, High school
Formats: Pre/post, Multiple-choice, Multiple-response
30 min

Wave Diagnostic Test (WDT)
Waves / Optics Content knowledge (waves)
Levels: Intermediate, Intro college, High school
Formats: Pre/post, Multiple-choice, Multiple-response, Short answer
Long: 30 min, Short: 15 min

Four-tier Geometrical Optics Test (FTGOT)
Waves / Optics Content knowledge (plane mirrors, spherical mirrors, lenses)
Levels: Intro college
Formats: Pre/post, Multiple-choice
50 min

Mechanical Waves Conceptual Survey 2 (MWCS2)
Waves / Optics Content knowledge (propagation, superposition, reflection, standing waves)
Levels: Intro college
30 min

Waves / Optics Content knowledge (propagation, superposition, reflection, standing waves)
Levels: Intro college
Formats: Pre/post, Multiple-choice

Light Phenomena Conceptual Assessment (LPCA)
Waves / Optics Content knowledge (reflection, refraction, Snells law, wavelength and frequency, light scattering, electromagnetic spectrum, the human eye)
Levels: Intro college, High school
Formats: Multiple-choice
40 min

Wave Concept Inventory (WCI)
Waves / Optics Content knowledge (visualization of waves, mathematical depiction of waves, wave definitions)
Levels: Upper-level
Formats: Pre/post, Multiple-choice, Multiple-response
20 min

Survey of Thermodynamic Processes and First and Second Laws (short) (STPFaSL-short)
Thermal / Statistical Content knowledge (first law of thermodynamics, second law of thermodynamics, PV diagrams, reversible processes, irreversible processes)
Levels: Intro college
Formats: Pre/post, Multiple-choice
40 min

Thermal Concept Evaluation (TCE)
Thermal / Statistical Content knowledge (temperature, heat transfer, phase change, thermal properties of materials)
Levels: Intro college, High school
Formats: Pre/post, Multiple-choice
30 min

Thermodynamic Concept Survey (TCS)
Thermal / Statistical Content knowledge (temperature, heat transfer, ideal gas law, first law of thermodynamics, phase change, thermal properties of materials)
Levels: Intermediate, Intro college
Formats: Multiple-choice
35 min

Thermal and Transport Concept Inventory: Thermodynamics (TTCI-T)
Thermal / Statistical Content knowledge (second law of thermodynamics, energy quality, conversion of thermal energy to work, enthalpy, internal energy, equilibrium processes, steady-state processes)
Levels: Intermediate
Formats: Pre/post, Multiple-choice

Heat and Temperature Conceptual Evaluation (HTCE)
Thermal / Statistical Content knowledge (temperature, phase change, heat transfer, thermal properties of materials)
Levels: Intro college
Formats: Pre/post, Multiple-choice, Short answer
40 min

Survey of Thermodynamic Processes and First and Second Laws (long) (STPFaSL-long)
Thermal / Statistical Content knowledge (PV diagrams, reversible processes, irreversible processes, first law of thermodynamics, second law of thermodynamics)
Levels: Upper-level, Intermediate, Intro college
Formats: Pre/post, Multiple-choice
50 min

Thermodynamics Concept Inventory (TCI)
Thermal / Statistical Content knowledge
Levels: Intro college
Formats: Pre/post, Multiple-choice

Quantum Mechanics Concept Assessment (QMCA)
Modern / Quantum Content knowledge (wave functions, measurement, time dependence, probability, infinite square well, 1D tunneling, energy
50 min

RESOURCE LETTER

Resource Letters are guides for college and university physicists, astronomers, and other scientists to literature, websites, and other teaching aids. Each Resource Letter focuses on a particular topic and is intended to help teachers improve course content in a specific field of physics or to introduce nonspecialists to this field. The Resource Letters Editorial Board meets at the AAPT Winter Meeting to choose topics for which Resource Letters will be commissioned during the ensuing year. Items in the Resource Letter below are labeled with the letter E to indicate elementary level or material of general interest to persons seeking to become informed in the field, the letter I to indicate intermediate level or somewhat specialized material, or the letter A to indicate advanced or specialized material. No Resource Letter is meant to be exhaustive and complete; in time there may be more than one Resource Letter on a given subject. A complete list by field of all Resource Letters published to date is at the website http://ajp.dickinson.edu/Readers/resLetters.html. Suggestions for future Resource Letters, including those of high pedagogical value, are welcome and should be sent to Professor Roger H. Stuewer, Editor, AAPT Resource Letters, School of Physics and Astronomy, University of Minnesota, 116 Church Street SE, Minneapolis, MN 55455; e-mail: rstuewer@physics.umn.edu

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Resource Letter ALIP–1: Active-Learning Instruction in Physics

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This Resource Letter provides a guide to the literature on research-based active-learning instruction in physics. These are instructional methods that are based on, assessed by, and validated through research on the teaching and learning of physics. They involve students in their own learning more deeply and more intensely than does traditional instruction, particularly during class time. The instructional methods and supporting body of research reviewed here offer potential for

What is “Research-based Active-Learning Instruction”?

(as defined by Meltzer and Thornton, 2012)

- It is explicitly based on research in teaching and learning of a *specific discipline*
- Incorporates activities that require students to express their thinking through speaking, writing, or other actions
- Tested repeatedly and shows evidence of improved student learning

VI. ACTIVE-LEARNING INSTRUCTIONAL MATERIALS FOR INTRODUCTORY ALGEBRA- AND CALCULUS-BASED PHYSICS COURSES

We include here selected references to research-validated instructional materials and to papers that provide information regarding implementation and effectiveness of the materials. Materials within each of Secs. VI A–E are organized in chronological order of most recent publication of the primary (first) reference, which in some cases is years or decades after the publication date of the original version of the materials; additional references within subsections are organized chronologically; otherwise, organization is alphabetical.

A. Materials primarily for use in lecture sessions or lecture-based courses

1. Peer Instruction

104. **Peer Instruction: A User's Manual**, E. Mazur (Prentice Hall, Upper Saddle River, NJ, 1997). Peer Instruction is a method of interactive lecturing; short segments of a lecture are interspersed with students working collaboratively to answer qualitative, conceptual multiple-choice questions ("ConcepTests"). Provides an overview of the method and a large collection of ConcepTests. (E)

105. "Peer Instruction: Ten years of experience and results," C. H. Crouch and E. Mazur, Am. J. Phys. **69**, 970–977 (2001). Detailed documentation of improved student learning in physics lecture courses at Harvard that were based on Peer Instruction. (E)

106. "Transforming the lecture-hall environment: The fully interactive physics lecture," D. E. Meltzer and K. Manivannan, Am. J. Phys. **70**, 639–654 (2002). Review of active-learning instruction in physics and description of the "fully" interactive lecture. This variant of Peer

B. Materials primarily for the laboratory

1. Socratic Dialog-Inducing Labs

117. "Socratic pedagogy in the introductory physics laboratory," R. R. Hake, Phys. Teach. **30**, 546–552 (1992). "SDI" labs (Ref. 63) are designed to promote mental construction of concepts through conceptual conflict, analysis using multiple representations, peer discussion, and Socratic dialogue with instructors. Curricular materials are archived at <http://www.physics.indiana.edu/~sdi/>. (E)

2. Tools for Scientific Thinking

118. **Tools for Scientific Thinking: Motion and Force Curriculum and Guide;** and **Heat and Temperature**

C. Hybrid lecture-lab materials

1. Cooperative Group Problem Solving

124. University of Minnesota Physics Education Research and Development, *Cooperative Group Problem Solving*: <http://groups.physics.umn.edu/physed/Research/CGPS/CGPSintro.htm>. Comprehensive approach to restructuring introductory physics courses, based on work

D. Tutorials and problem-solving worksheets

1. Tutorials in Introductory Physics

136. **Tutorials in Introductory Physics; Homework for Tutorials in Introductory Physics; Instructor's Guide**

E. Computer simulations and intelligent tutors

1. MasteringPhysics

143. "What course elements correlate with improvement on tests in introductory Newtonian mechanics?" E.-S. Morote and D. E. Pritchard, Am. J. Phys. **77**, 746–753 (2009). "MasteringPhysics" is an online homework system with self-paced tutorials that incorporate extensive hints and feedback based on physics education research. This study showed that use of an early version correlated more strongly with high performance on both the MIT final course exam and the FCI (Ref. 72) than other course elements such as written homework, group problem solving, and class participation. The system was originally developed by D. E. Pritchard of MIT but is currently owned by Pearson Education; see: <http://www.masteringphysics.com/site/index.html>. (E)

2. Andes

144. "The Andes physics tutoring system: An experiment in freedom," K. VanLehn, B. van de Sande, R. Shelby, and S. Gershman, in **Advances in Intelligent Tutoring Systems [Studies in Computational Intelligence 308]**, edited by R. Nkambou, J. Bourdeau, and R. Miz-

VII. ACTIVE-LEARNING INSTRUCTIONAL MATERIALS FOR INTERMEDIATE- AND ADVANCED-LEVEL PHYSICS COURSES

Material following the first reference within subsections is organized chronologically.

A. Mechanics

149. **Intermediate Mechanics Tutorials**: <http://umaine.edu/per/projects/imt/>. Contains a large collection of pretests, tutorials, exam questions, homework, and instructor's guides for a wide variety of topics in upper-level mechanics, modeled after the University of Washington's **Tutorials in Introductory Physics** (Ref. 136). (E)

150. "Investigating student understanding in intermediate mechanics: Identifying the need for a tutorial approach to instruction," B. S. Ambrose, Am. J. Phys. **72**, 453–459 (2004). Discussion of research on which **Intermediate Mechanics Tutorials** are based, along with some student-learning data that demonstrate effectiveness of some of the materials. (E)

B. Electricity and magnetism

151. **University of Colorado, Junior-level Electricity and Magnetism Course Materials**: <http://www.colorado.edu/sei/departments/physics_3310.htm>. Includes tutorials, ConcepTests (Ref. 104) for interactive lectures, homework, lecture notes, and very detailed instructor's notes. (E)

152. "Longer term impacts of transformed courses on student conceptual understanding of E&M," S. J. Pollock and S. V. Chasteen, in **2009 Physics Education Research Conference**, edited by M. Sabella, C. Henderson, and C. Singh, AIP Conference Proceedings **1179** (AIP, Melville, NY, 2009), pp. 237–240. Students in a course using research-based materials (Ref. 151) did significantly better on a diagnostic exam than students in the traditionally taught course. Also see

C. Optics

153. "Active learning in intermediate optics through concept building laboratories," M. F. Masters and T. T. Grove, Am. J. Phys. **78**, 485–491 (2010). Laboratory approach relying on direct confrontation of misconceptions through experimental tests of predictions. Materials available at <http://users.ipfw.edu/masters/Optics%20CCLI%20Project/optics_ccli_project.htm>. (E)

D. Thermal physics

154. **Physics Education Research in Thermal Physics:** <http://thermoper.wikispaces.com/>. Materials targeted at upper-level thermal physics courses; some are also useful for introductory courses. (E)

155. "Student ideas regarding entropy and the second law of thermodynamics in an introductory physics course," W. M. Christensen, D. E. Meltzer, and C. A. Ogilvie, Am. J. Phys. **77**, 907–917 (2009). Provides evidence for effectiveness of some of the materials in introductory and sophomore-level courses. (E)

156. "Student understanding of basic probability concepts in an upper-division thermal physics course," M. E. Loverude, in **2009 Physics Education Research Conference**, edited by M. Sabella, C. Henderson, and C. Singh, AIP Conference Proceedings **1179** (AIP, Melville, NY, 2009), pp. 189–192. This and the following reference provide promising, albeit ambiguous, evidence of student learning gains in upper-level courses using the thermal physics curricular materials. (E)

157. "Investigating student understanding for a statistical analysis of two thermally interacting solids," M. E. Loverude, in **2010 Physics Education Research Conference**, edited by C. Singh, M. Sabella, and S. Rebello, AIP Conference Proceedings **1289** (AIP, Melville, NY, 2010), pp. 213–216. (E)

E. Modern physics and quantum mechanics

These materials are organized chronologically. In addition to the following sources, curricular materials on modern physics and quantum mechanics are included in Volume 2 of **Activity-Based Tutorials** (Ref. 140).

158. **Physlet® Quantum Physics: An Interactive Introduction to Quantum Theory**, M. Belloni, W. Chris-

VIII. ACTIVE-LEARNING INSTRUCTIONAL MATERIALS FOR PRESERVICE TEACHERS AND NONSCIENCE STUDENTS

Materials in this section are primarily targeted at courses for nontechnical students who take physics to fulfill general-education requirements or as part of an elementary-teacher-education program. However, the materials are generally quite useful as supplements for many other types of courses as well. Subsections are organized chronologically according to most recent publication date of the first reference within each section; references within subsections are organized chronologically.

A. Physics by Inquiry

164. **Physics by Inquiry**, L. C. McDermott and the Physics Education Group at the University of Washington (Wiley, New York, 1996), Vols. I and II. Detailed activity guide that integrates quantitative and qualitative problem-solving exercises, hands-on laboratory activities, and expository text. A broad range of physical-science topics is included. Development of these

B. Constructing Physics Understanding

167. "Using computers to create constructivist learning environments: Impact on pedagogy and achievement," D. Huffman, F. Goldberg, and M. Michlin, J. Comput. Math. Sci. Teach. **22**(2), 151–168 (2003). Describes an implementation and assessment of the Constructing Physics Understanding (CPU) curriculum, targeted at nontechnical students. On-screen prompts guide students to make and test predictions with both real and simulated experiments. Description and sample activities are at <http://cpucips.sdsu.edu/web/cpu/>. (E)

C. Intuitive Quantum Physics

168. "Laboratory-tutorial activities for teaching probability," M. C. Wittmann, J. T. Morgan, and R. E. Feeley, Phys. Rev. ST Phys. Educ. Res. **2**, 020104 (2006). Documents improved student learning of some probability concepts after use of the relevant tutorial from the "Intuitive Quantum Physics" project, archived at <http://umaine.edu/per/projects/iqp/>. (E)

D. Inquiry into Physical Science

169. **Inquiry into Physical Science: A Contextual Approach, Second Edition; Vol. 1, Global Warming; Vol. 2, Kitchen Science; Vol. 3, The Automobile**, R. Nanes (Kendall Hunt, Dubuque, IA, 2008). An inquiry-based activity guide that uses everyday contexts to initiate explorations into fundamental concepts in physics and chemistry. Targeted at preservice elementary

E. Physics & Everyday Thinking

171. **Physics & Everyday Thinking**, F. Goldberg, S. Robinson, and V. Otero (It's About Time, Armonk, NY, 2008). Detailed activity guide targeted especially at prospective elementary-school teachers and other nonscience students; makes heavy use of computer-assisted tools and computer simulations. Puts strong emphasis on students expressing and reflecting on their own ideas, and explicitly comparing and contrasting their thinking with that of scientists and other students. (E)

172. "Attitudinal gains across multiple universities using the Physics and Everyday Thinking curriculum," V. K. Otero and K. E. Gray, Phys. Rev. ST Phys. Educ. Res. **4**, 020104 (2008). In surveys of 182 students in nine courses at multiple institutions that used the **Physics & Everyday Thinking** curriculum (or a variant of it), "expert-like" attitudes on the CLASS instrument (Ref. 89) showed significant increases from pre- to post-instruction. This was in striking contrast to the findings of most other courses previously surveyed with the CLASS or similar instruments. (E)

173. "Design principles for effective physics instruction: A case from physics and everyday thinking," F. Goldberg, V. Otero, and S. Robinson, Am. J. Phys. **78**, 1265–1277 (2010). Detailed description of the design principles of **Physics & Everyday Thinking** with evidence for student learning gains; includes extensive analysis of actual student classroom transcripts to illustrate the principles in action. (E)

Some common characteristics of research-based active-learning instruction (Meltzer and Thornton, 2012)

A. Instruction is informed and explicitly guided by research on student learning

- Various diagnostic instruments are used to explore and assess students’ thinking
- Curriculum development is guided and assessed by continuing research

B. Specific student ideas are elicited and addressed

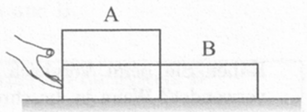
- A wide variety of methods has been used to draw out students’ ideas and build curriculum and instruction around those ideas
- One example: University of Washington Tutorials

Im vorliegenden Arbeitsblatt untersuchen wir Kräfte auf bewegte Systeme. Wir verwenden dabei die gleiche Betrachtungsweise wie in Arbeitsblatt 1 (*Kräfte*) im Teil I (*Statik*) dieser Lehrmaterialien.

1 Anwendung der Newton'schen Gesetze auf wechselwirkende Körper

1.1 Konstante Geschwindigkeit

Drei gleiche Ziegelsteine werden mit *konstanter* Geschwindigkeit über die Oberfläche eines Tisches geschoben. Die Hand schiebt dabei waagerecht (siehe Abbildung). Zwischen den Steinen und dem Tisch tritt Reibung auf. Die beiden linken Steine werden als System A und der rechte Stein wird als System B bezeichnet.



a) Vergleichen Sie die auf System A wirkende *resultierende Kraft* (nach Betrag und Richtung) mit der resultierenden Kraft auf System B. Begründen Sie Ihre Antwort.

b) Zeichnen Sie jeweils ein Freikörperbild für System A und System B. Kennzeichnen Sie alle Kräfte in Ihren Diagrammen durch Angabe der folgenden Informationen: die Art der Kraft, den Körper, auf den sie wirkt, und den Körper, der sie ausübt.

Freikörperbild für System A	Freikörperbild für System B

c) Ist der Betrag der Kraft, die System B auf System A ausübt, *größer*, *kleiner* oder *gleich* dem Betrag der Kraft, die System A auf System B ausübt? Begründen Sie.

Wie würde sich Ihre Antwort ändern, wenn die Hand System B nach links schieben würde, anstatt System A nach rechts zu schieben? Falls Ihre Antwort in diesem Fall gleich bleibt, erklären Sie, warum.

d) Kennzeichnen Sie sämtliche auftretenden Newton'schen Kräftepaare in Ihren Freikörperbildern mithilfe eines oder mehrerer Kreuze (×) an jedem der beiden Kräftepfeile eines Paares. (Markieren Sie also beide Vektoren des ersten Paares durch →×→, beide Vektoren des zweiten Paares durch →××→ usw.)

Nach welchen Kriterien haben Sie die Newton'schen Kräftepaare identifiziert? Wie lässt sich die in Arbeitsblatt 1 eingeführte Notation (z. B. $\vec{F}_G^{KE}$ für die Gewichtskraft, die von der Erde auf die Kiste ausgeübt wird) hierfür nutzen?

e) Sind Ihre Antworten in c) mit den von Ihnen gefundenen Newton'schen Kräftepaaren in d) vereinbar? Wenn ja, geben Sie an, wie. Wenn nicht, lösen Sie den Widerspruch auf.

KINETIK
Zweites und drittes Newton'sches Gesetz

C. Kautz et al., *Tutorien zur Technischen Mechanik*, https://doi.org/10.1007/978-3-662-56758-6_30

b) Zeichnen Sie jeweils ein Freikörperbild für System A und System B. Kennzeichnen Sie alle Kräfte in Ihren Diagrammen durch Angabe der folgenden Informationen: die Art der Kraft, den Körper, auf den sie wirkt, und den Körper, der sie ausübt.

Freikörperbild für System A	Freikörperbild für System B

c) Ist der Betrag der Kraft, die System B auf System A ausübt, *größer*, *kleiner* oder *gleich* dem Betrag der Kraft, die System A auf System B ausübt? Begründen Sie.

We know from research that students have great difficulty with Newton's third law—that the forces that A and B exert on each other are *equal* and opposite—so students are asked to state their answer explicitly *and explain their reasoning*.

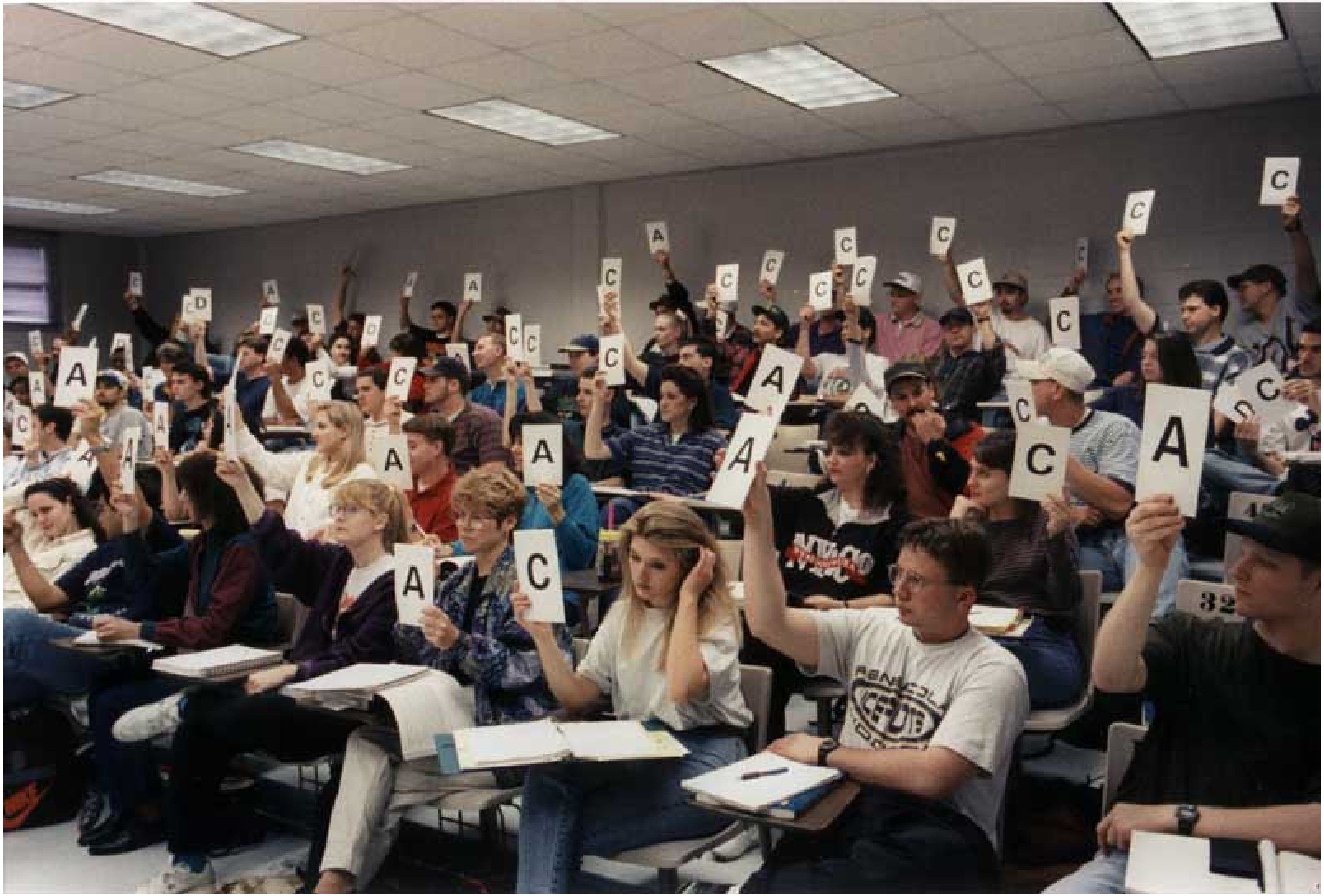
C. Students are encouraged to “figure things out for themselves”

- Ask “leading questions” to guide students in a certain direction, *before* providing detailed formulations of generalized principles
- Ask students to offer predictions regarding the outcome of experiments, to debate various hypotheses, and to test them through experimentation


SIU

D. Students engage in a variety of problem-solving activities during class time

- Hands-on experiments
- Questions requiring quantitative and/or qualitative responses
- Multiple-choice conceptual questions answered with a classroom communication system

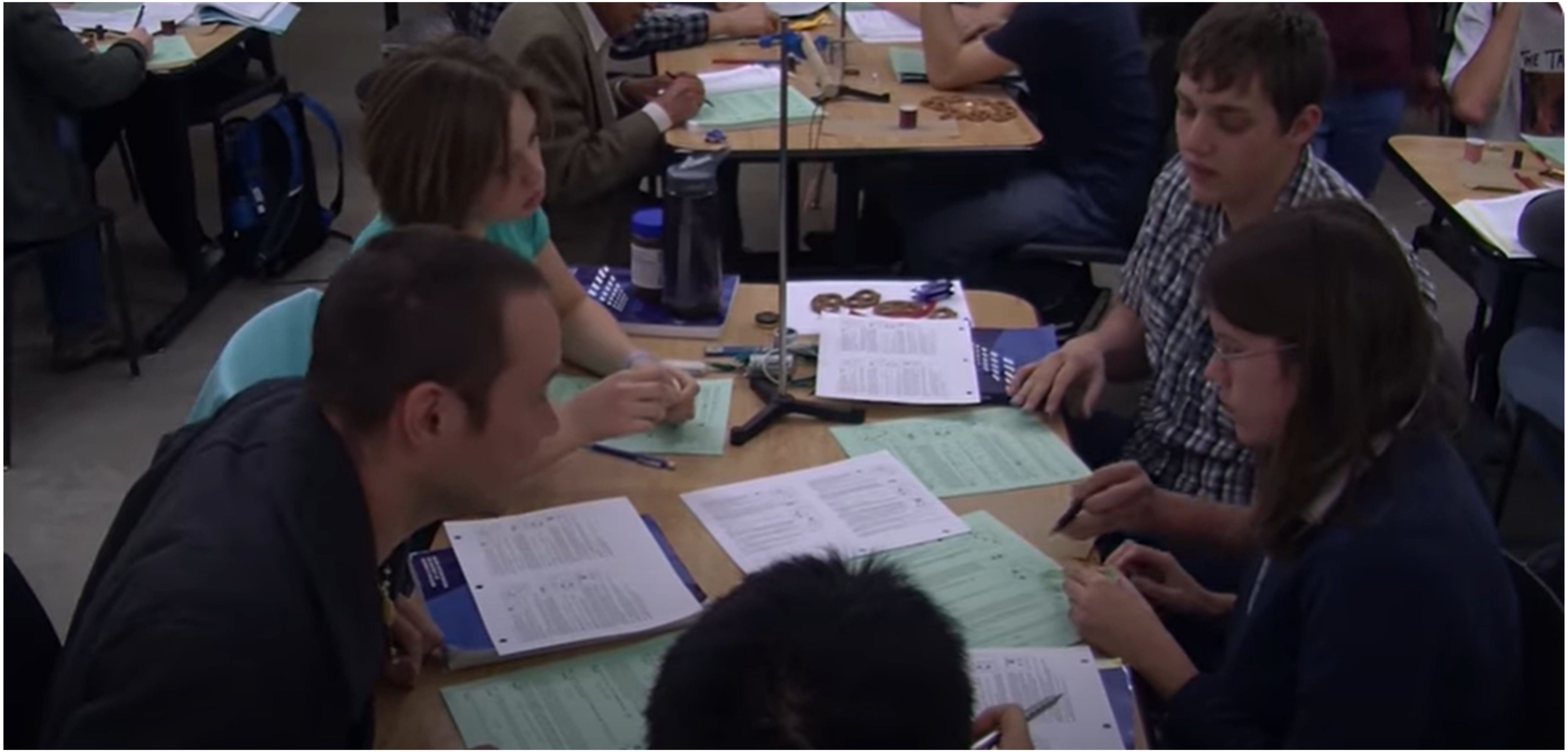


E. Students express their reasoning explicitly

- Students can express their reasoning:
  - Verbally, with instructors and other students
  - In writing, on quizzes, homework, exams, and worksheets

F. Students often work together in small groups

- Group work helps students express their own thinking, and comment on and critique each other’s thinking



Tutorial in Introductory Physics at the University of Colorado

G. Students receive *rapid* feedback

- “Rapid” may mean minute-to-minute, or even faster
- Feedback from instructors through *frequent* questions and answers
- Feedback from fellow students through small-group interactions

Tutorial in Introductory Physics at the University of Colorado

H. Qualitative reasoning and conceptual thinking is emphasized

- Non-quantitative means of problem solving are emphasized to strengthen students’ understanding of fundamental concepts

Summary

- The development of research-based active-learning instruction in physics has been a 200-year-long process, still ongoing
- Many other STEM fields have participated in the pedagogical developments illustrated here through physics
- The future of improved STEM education may be based on the more comprehensive research on the teaching and learning of specific STEM disciplines