

ARCHAEOLOGY OF A BOOKSTACK: SOME MAJOR INTRODUCTORY PHYSICS TEXTS OF THE LAST 150 YEARS

Beyond its teaching purpose, a textbook of introductory physics is also a historical document. It contains the physics and the pedagogy of its authors and their times, and reflects the era in which it was written. This article—paralleling an exhibit prepared by the American Physical Society's forum on education for display at the APS centennial celebration in Atlanta this month—examines historical aspects of introductory physics texts. It begins with a 19th-century text, Ganot's *Physics*, and then works up to the present, examining various editions of popular introductory college-level texts by Millikan, Franklin, Duff, Sears and Zemansky, and Halliday and Resnick (figure 1). It is interesting to see what has changed in the teaching of introductory physics over the last 150 years and what has remained the same.

The content of these books has changed to follow the remarkable advances in physics during the period—although less, perhaps, than one might expect and rather slowly. The problems of physics teaching, however, have remained much the same. The physics teachers of 1899, like those of 1999, complained of declining enrollments and lack of student motivation. Some asserted the need for hands-on experimentation; others proclaimed the inefficacy of hands-on experimentation. Some urged that students be actively engaged, and others worried over the impracticality of engaging them in large numbers. In every decade, there has been debate over the level of mathematics and mathematical preparation appropriate for beginning physics. Some authors offer descriptive physics; others emphasize its analytical aspects. There have been frequent calls for changes in content and for changed modes of presentation.

On the threshold: Ganot's physics

One of the most successful 19th-century physics texts was *Traité élémentaire de physique expérimentale et appliquée et météorologie* by Adolphe Ganot (1804–87).¹ Although designed for teaching the well-defined, rather rigid syllabus of the French *lycées*, it was used all over the world. The first English edition, *Elementary Treatise on Physics, Experimental and Applied, for the Use of Colleges and Schools*, was prepared in 1863 by the British physicist and chemist Edmund Atkinson and was commonly known as Atkinson's *Ganot* or as Ganot's *Physics*.

Atkinson's *Ganot* was widely used in the US in the

Changing styles in high school and college physics texts reveal an evolution in teaching methods, but we can also see signs of the same debates that continue today.

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1870s and 1880s. Albert Michelson learned physics from it at the US Naval Academy in 1870.² Robert A. Millikan remembered regretfully that his first course in physics at Oberlin College in 1888–89 had been taught using a text “greatly inferior to Ganot's *Physics*, which had theretofore been used.”³ At Williams College, *Ganot* was the principal physics text from 1873 until 1892. *Ganot* was still in use at Columbia University in 1894. Reminiscing in a special issue of *PHYSICS TODAY* in 1981 (November, page 253), Emilio Segrè revealed that his interest in physics had first been aroused by “A. Ganot, *Treatise on Physics*, Italian translation of 1863, which I found when I was about 10 years old among the books of an uncle.”

Ganot's *Physics* is representative of texts and pedagogy of the mid-19th century. It presents a sequence of handsome woodcuts of practical devices or demonstration or measuring apparatus, along with a thorough description of the operation of each. They are complete enough that the book can serve today as a useful encyclopedia of forgotten apparatus. The book's description brought home to me in a new lively way the ingenuity of Atwood's machine (see figure 2).

Keeping a physics textbook up to date was as difficult then as it is now. In some ways *Ganot* was exceptionally responsive to new physics; the 1893 edition (put out six years after Ganot's death) included a short description of Heinrich Hertz's experimental verification that light is an electromagnetic phenomenon, even though Hertz's work was only a few years old. But updating the text with new concepts proceeded much more slowly than the inclusion of new phenomena. The Hall effect offers an example of the incorporation of a new phenomenon with no discussion of the underlying concept. Edwin H. Hall had discovered the effect in 1879 while doing doctoral research at Johns Hopkins University, and the 1893 edition of *Ganot* devoted a page to describing how to produce the effect experimentally and how it shows the deflection of currents by a magnetic field, but there was no mention of charge carriers or their signs. This is not surprising, for only around 1890 did the concept of electric charge as a material entity begin to replace James Clerk Maxwell's view of charge as some nonmaterial singularity or vortex in the electric field.⁴

By 1893, *Ganot's* encyclopedic, descriptive presentation was falling out of favor, but certain features having to do with the marketing of a successful text are still evident in today's textbook industry. Like many popular texts then and now, *Ganot's Physics* outlived its creators.

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**Resnick, Halliday
& Krane 4th ed.
1992**

**Halliday & Resnick
1960**

**Sears & Zemansky
1948**

Sears 1944

Millikan 1938

Duff 1920

Duff 1908

Millikan 1908

Millikan 1902

Ganot 1863

The 30th French edition came out 47 years after Ganot's death; the last revision of Atkinson's *Ganot* occurred in 1910, a decade after Atkinson's death. The succession of revisions that kept the book commercially useful also steadily lengthened it. The first English-language edition in 1863 of Ganot's *Physics* contained 780 pages; the 1910 revision, after 18 editions of fairly steady growth, contained 1225 pages. Then as now, publishers enlarged the market for their books by producing abridged versions adapted for "schools and academies" and "for general readers and young persons." Then as now, a successful text tended to immortality, obesity and proliferation.

Pedagogy for a new era: Laboratory-centered instruction

Ganot's text lay firmly within the tradition of passive learning. Michelson's students at the University of Chicago remember his lectures as very polished; they also remember they were forbidden to interrupt with questions.

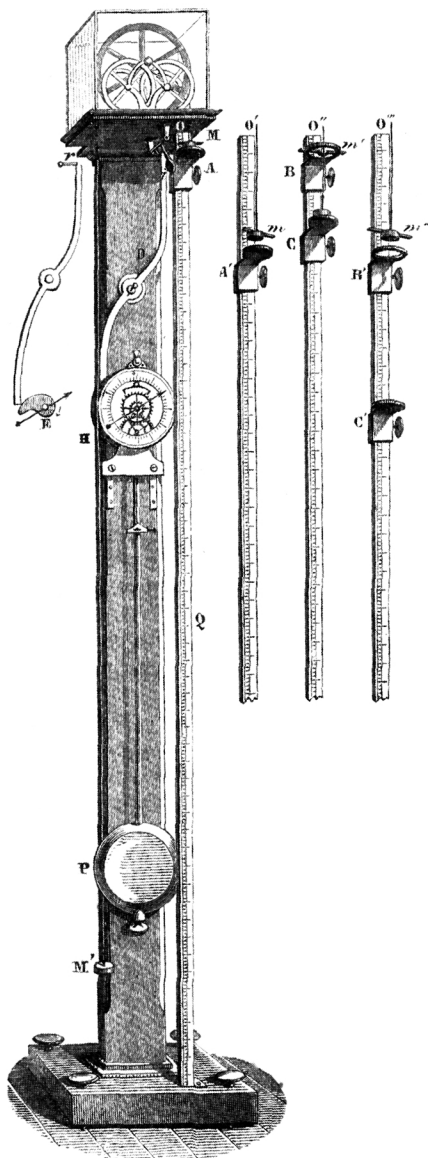
FIGURE 1. INTRODUCTORY PHYSICS bookstack, spanning the last 150 years. Their content and approach have changed, but not as much as you might expect given the enormous advances in physics. The labeled books are discussed in this article.

The Ganot text is like that: It describes; the reader absorbs. There is no hint that a student might use apparatus or perform demonstrations. The movement toward a pedagogy that more directly involves the student eventually made the book obsolete in America.

Beginning in the 1870s, a movement arose in the US to make laboratory work integral to the teaching of physics (and chemistry). The instigators of the changes in physics education were mainly teachers of physics in high schools and academies. The reform effort was a national one, but it was particularly strong in Massachusetts where it became public policy. In 1881 the superintendent of Boston Schools wrote that "the mind gains a real and adequate knowledge of things only in the presence of the things themselves." Alfred Gage, an instructor at the English High School of Boston, was an ardent proponent of laboratory work and wrote several widely used texts to support this approach. Gage's 1882 text, *A Text-Book on the Elements of Physics for High Schools and Academies*,⁵ was the first American text to emphasize student experiments and came to be widely used.

If Gage's emphasis on laboratory-based learning sounds modern, we should note that in one plan of experimentation he allocated 12 minutes to each experiment so that students could do five experiments in an hour. That Gage did not subscribe to the dictum "Less is more" is made entirely clear when we read the following in the preface to his 1895 text, *The Principles of Physics*: "Meagre information results in hazy comprehension, and consequently provokes but meagre interest. Full and varied treatment, on the contrary, by presenting different points of view, clears the conceptions and thus provokes interest, and allures to continued study. All things considered, *too much* in a text-book is far preferable to *too little* (emphasis in original)."⁶

Shortly after Edwin H. Hall arrived at Harvard in 1881 as an instructor in physics, he was asked to prepare a list of 40 laboratory exercises for use in schools as part of the requirements for admission to the college. The result, published in 1886 as the *Harvard Descriptive List of Elementary Physical Experiments*, described the details of the experiments so well "that even the ill-prepared and meagerly budgeted teachers of that day could take the Descriptive List and put it into action. . . ."⁷ After the list was picked up by the National Educational Association and renamed the *National Physics Course*, and after apparatus manufacturers began supplying complete kits of equipment for performing the experiments, the list became more than admission requirements for entrance to Harvard. It became the *de facto* national standard for instruction in American high schools and academies.⁸



Millikan's books

This emphasis on laboratory-based physics instruction is reflected in the physics textbooks of Robert A. Millikan. Although widely known today for his Nobel Prize-winning experimental investigations of the photoelectric effect and the electron's charge, during the first 12 years of his professional career, Millikan concentrated on teaching and writing textbooks. He was attracted to the University of Chicago in 1896, just four years after its founding, by Michelson, America's premier experimental physicist of the day. Once there, however, as a junior faculty member, Millikan was assigned a big part of the job of organizing the undergraduate physics courses of the new university. That work led him to write physics textbooks for both high school courses and college courses.

In his preface to the 1902 edition of *Mechanics*, *Molecular Physics and Heat*, Millikan succinctly distinguished the goals of high school physics courses from those of college courses: "Since the book represents a college, not a high school, course, the aim has been, not so much

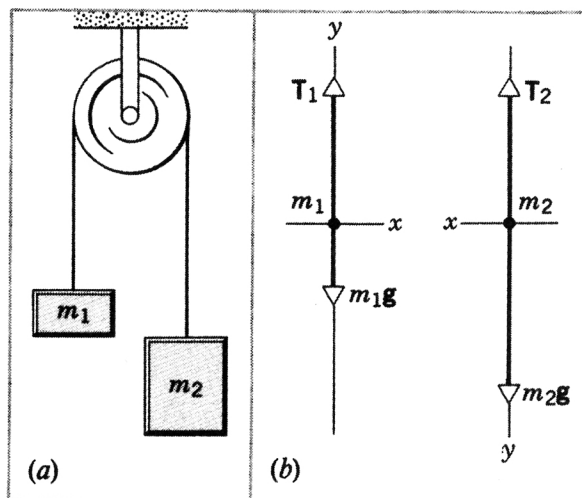


FIGURE 2. TWO ATWOOD MACHINES, reflecting the increasing abstractness of introductory physics texts over time. **Left:** Ganot's handsome woodcut from about 1853 (and all later editions) shows an Atwood machine in complete detail. When an extra weight unbalances one side, the weights accelerate until the excess weight is picked off by a ring. This engages the pendulum clock which is used to time the constant motion with which the now balanced weights move. **Above:** The picture from the 1992 edition of Resnick, Halliday and Krane includes a diagram of the forces but has no details of an actual apparatus.

to acquaint the student with interesting and striking phenomena, as to give him an insight into the real significance of physical things—to introduce him to the very heart of the subject by putting him in touch with the methods and instruments of modern physical instrumentation, and by carrying him through processes of close reasoning by which the present science of Physics has been developed.”⁹

Although Millikan closely connected his material to well-defined laboratory experiments, he assured his readers that “experiments have been made incidental to the study of principles, not principles incidental to the study of experiments.”⁹ The tension that opposes the teaching of principles to putting the student in direct touch with laboratory instruments reflected waning enthusiasm for laboratory-centered instruction, especially among the high school teachers who had initiated the movement more than 20 years earlier. Millikan acknowledged that “the most serious criticism which can be urged against modern laboratory work in Physics is that it often degenerates into a servile following of directions, and thus loses all save a purely manipulative value. . . . [I]t can not be too strongly emphasized that it is *grasp of principles*, not *skill in manipulation* which should be the primary object of General Physics courses (emphasis in original).”⁹

Millikan's books were very successful, especially his high school texts. Those texts were well illustrated with pictures of great physicists and technological wonders of the moment. (See, for example, figure 5.) In the 1920 edition of his *Practical Physics*,¹⁰ for example, the section on kinematics contained a picture of a French 340 mm gun in action, and the section on Newton's laws showed a cream separator; in other sections, Millikan used pictures of a magnetic crane loading pig iron (for a discussion of electromagnets, Hans Christian Ørsted and Joseph Henry), a locomotive (for James Joule and James Watt),



FIGURE 3. MILLIKAN READING TO HIS TWO SONS IN 1908. His physics texts were commercially quite successful, especially his high school text which was widely used for more than thirty years. In 1907 Millikan used book royalties to build a house in Chicago [John L. Michel, in *The Michelson Era in American Science, 1870-1930*, S. Goldberg and R. Stuewer, eds. AIP, NY, 1988.], probably the one in which he is sitting here. (Courtesy of the Archives, California Institute of Technology.)

a submarine (for Archimedes) and a flat iron and fuses (for Georg Ohm). His way of updating succeeding editions of this and other books was mainly to change the pictures, rather than the text.

Millikan also updated by accretion. In the last chapter of the 1922 edition of *Practical Physics*, there appeared six new sections—on modulated continuous waves as well as, in his words, “a method of producing them, the vacuum tube, transfer of energy through a condenser, the receiving station and the transmitting station.” Trying to lure students to physics by showing them marvels is not a new idea; Millikan wrote his high school texts so that “such subjects, and only such subjects, have been included as touch most closely the everyday life of the average pupil.”

Physics for engineers

Physicists have a deep interest in teaching physics to engineering students; the task creates many teaching jobs for physicists and a market for many textbooks. One such teacher and author was William S. “Pete” Franklin, an exuberant producer of some 25 textbook volumes. He taught at Lehigh University for 18 years (1897–1915) and then at MIT for 12 years (1917–29). His indignations are still current among physics teachers; the box on page 55 shows a complaint of the familiar “I told them, and I told them, and they still don’t get it!” variety.¹¹

Interest in what physicists can offer engineering students has recently been heightened by revisions in accreditation criteria proposed by ABET, the Accreditation Board for Engineering and Technology. (See *PHYSICS TODAY*, January 1999, page 59.) As Franklin’s role in engineering education shows, this interest is not new. Indeed, APS was involved as early as 1922, when A. Wilmer Duff, professor of physics at Worcester Polytechnic Institute and chairman of the APS educational committee, wrote the committee’s first report, *The Teaching of Physics with*

Especial Reference to the Teaching of Physics to Students of Engineering. However, the APS council’s unwillingness to adopt the report’s recommendations, and its discontinuation of the educational committee in 1927, helped motivate the founding of the American Association of Physics Teachers in 1930. Duff was also the principal author of *A Textbook of Physics*, a collaboration with separate authors for each of its seven major sections. Duff wrote one of the sections and edited and contributed to the others to provide overall consistency and unity. The book was aimed at engineering students and sold some 130 000 copies between 1908 and 1938. Melba Phillips has described it as the “Sears and Zemansky or Halliday and Resnick of the time.”¹²

Sears and Zemansky: Up a level

It is surely not a coincidence that the next major introductory physics textbook was written by an MIT professor with many years of experience teaching engineers. Between 1944 and 1946, Addison-Wesley brought out the first editions of the three volumes of Francis W. Sears’s *The Principles of Physics*. They were the progenitors of the immensely successful *College Physics* and *University Physics* that Sears coauthored with Mark Zemansky. These two books defined a new standard for introductory physics texts, even though the topics covered were quite conventional in selection and sequence. Mechanics, heat, sound, electricity and magnetism, and light took up the first 957 pages of the 1960 edition of *College Physics*; only in the last 36 pages did one find “atomic physics”—spectra, the Bohr model, x rays, radioactivity, the neutron, fission and fusion. The titles of the major sections were quite similar to those in Ganot’s *Physics* 50 years earlier. Nevertheless, the style of presentation was new and fresh; it was much less encumbered by discursive descriptions of apparatus and devices. Details of technology were also

gone, and the narrative proceeded straightforwardly with a clarity of connection between example and general principle that was unusual at the time. The legible typography and clean layout reflected the authors' uncluttered presentation of physics.

Principles of Physics was developed for students in MIT's two-year introductory physics course, and there were predictions that its mathematical level would be too high for the general population of undergraduates elsewhere. Despite these warnings, the adaptations for a one-year introductory course (whether for the calculus-based *University Physics* or for the algebra-based *College Physics*) included mathematics of a consistently higher level than in earlier texts for a similar market. Nevertheless, the books in their various versions and editions sold more than a million copies. Beyond their undoubted high quality, one reason for their remarkable success was fortunate timing. They came on the market just as the successful end of World War II brought science in general and physics in particular to a pinnacle of popular respect in America. A flood of veterans returned from the war and filled engineering and science programs with mature, serious students willing and able to cope with a new level of physics education, a level that realized Pete Franklin's maxim: "The most important thing for a young man to acquire from his first course in physics is an appreciation of the necessity for precise ideas."¹³

The several editions for which Sears and Zemansky

were personally responsible spanned a generation. Although Sears died in 1975, and Zemansky in 1981, *University Physics* itself has lived on to its current ninth edition with Hugh D. Young and Roger A. Freedman as authors. There is now more modern physics in *University Physics*, but the major changes consist of added features to facilitate individual study—more worked examples, and more conceptual problems—and a fancier layout with more color, more photographs, more illustrations and more varied typography.

Sears and Zemansky grappled with the problem of how to include the physics of this century in their introductory texts, but they never satisfactorily solved it. In the third edition of *University Physics* Sears added an innovative presentation of the special theory of relativity, but removed it from the fourth edition on the grounds that it was too difficult for undergraduates. In 1960 the authors and publishers merged *University Physics* with *Introductory Atomic Physics* by M. Russell Wehr and James A. Richards to produce a hybrid, *Modern University Physics*, that proved to be unsuccessful.

The Great Eggplant: Up another level

The need for a more effective presentation of modern material plus widespread demands for accelerated and more rigorous science education set the stage for the eclipse of the Sears and Zemansky books.

In 1960, Wiley published *Physics for Students of Science and Engineering* by David Halliday and Robert Resnick. This book became the patriarch of a family of texts that supplanted the Sears and Zemansky books as the standard introductory physics text. By 1970, with sales of over a million, the patriarch was an imposing 1324 pages fat. Its dark purple binding led the authors to call it the Great Eggplant. An abbreviated version that enlarged the market was bound in orange and came to be known as the Great Pumpkin.

It is interesting that, like Sears's *Principles of Physics*, the Halliday and Resnick text was developed in an engineering milieu. The two authors signed the book contracts while both were at the University of Pittsburgh. But shortly thereafter, Resnick moved to Rensselaer Polytechnic Institute, and he now attributes an important part of the success of the book to the fact that every science and engineering student at RPI "took a four-semester introductory physics course that involved the entire physics faculty one way or another."

Like Sears and Zemansky a generation earlier, Halliday and Resnick were fortunate in their timing. The 1957 Soviet launch of Sputnik, Earth's first artificial satellite, threatened America's self-esteem if not its actual security. Public outcries demanding more and better science education were met with an outpouring of public money to reform the teaching of physics and to stimulate the education of more engineers and physicists. Resnick and Halliday

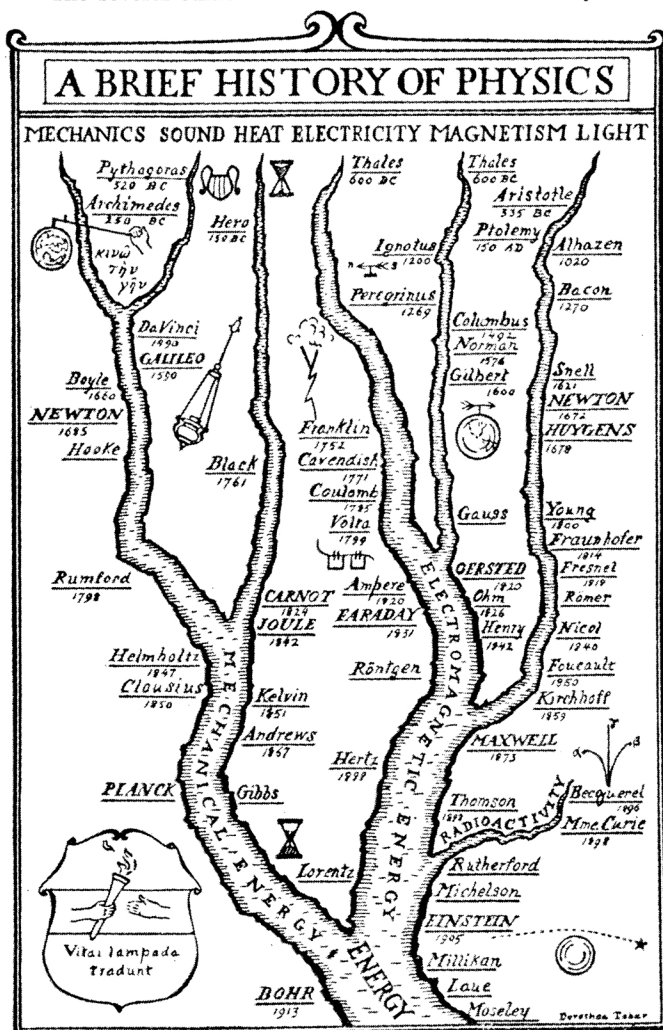


FIGURE 4. SYNOPTIC MAP OF PHYSICS from the 1925 edition of Duff's *College Physics*. In the upper left Archimedes' hand is using a lever to lift Earth; apparently he found a place to stand. Nearby is the swinging chandelier from which Galileo inferred the law of the pendulum. The hour glasses show time progressing from top to bottom. Near Einstein's name, the Sun is shown deflecting starlight. Although 25% of the map shows "modern" physics, less than 5% of the book discussed such topics.

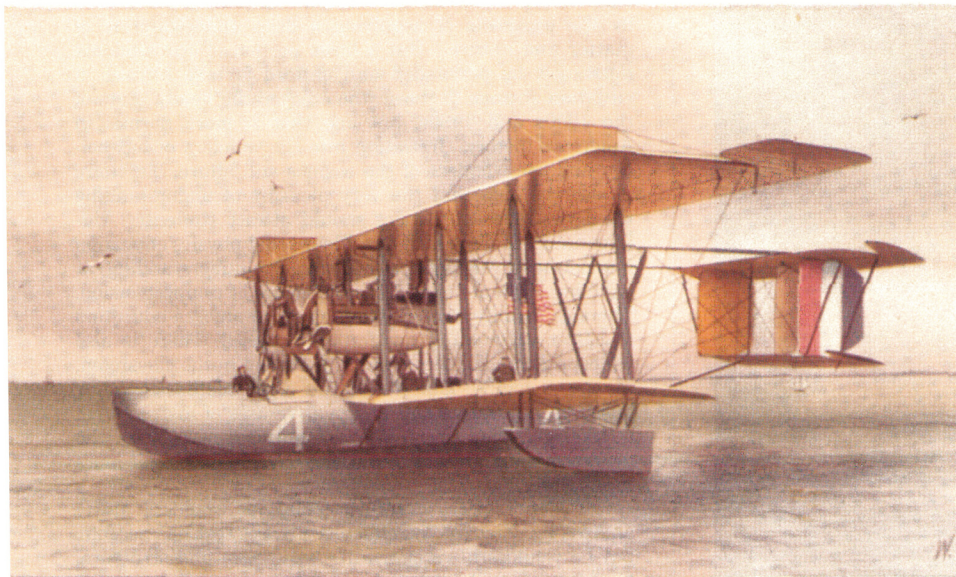


FIGURE 5. FIRST PLANE TO fly across the Atlantic. Millikan enlivened his texts with illustrations of current technological wonders. This picture of NC-4 appears as the frontispiece of the 1920 edition of *Practical Physics*, less than a year after it took 18 days to fly from Far Rockaway, New York to Lisbon, Portugal.

caught the crest of a rising wave with a book that preserved the traditional organization of introductory physics. It raised the level of abstraction further, emphasizing principles and the unity of physics while dropping such traditional topics as “simple machines, surface tension, viscosity, calorimetry, change of state, humidity, pumps, practical engines, musical scales, architectural acoustics, electrochemistry, thermoelectricity, motors, a.c. circuits, electronics, lens aberrations, color, photometry and others,”¹⁴—a list straight from the Sears and Zemansky table of contents.

I have a deep affection for H&R, as we called the book. Because I often taught from it during my first 15 years of teaching, H&R is where I really learned physics. I thought its problems were wonderful—although I am not sure my students did. Where Sears and Zemansky’s problems almost always asked for a numerical answer, problems in H&R usually wanted a general algebraic solution. This approach reflected H&R’s increased level of abstraction, part of a strategy to encompass the ever-expanding body of physics within its general principles. Another aspect of H&R’s higher level of abstraction was the full use of vector algebra with symbolic vectors and dot and cross products. Even vector calculus, in the form of line and surface integrals, was used to present the integral forms of Maxwell’s equations.

Although only 42 of the more than 1200 pages in the second edition (volume I, 1966; vol. II, 1962) were explicitly devoted to matter waves and the quantum aspects of light, H&R contains much more modern physics than its predecessors. Many modern topics were integrated into the traditional sections. For example, nuclear reactions and radioactive decay were introduced in the chapter on collisions, and James Chadwick’s determination of the existence and mass of the neutron was nicely presented as a problem at the chapter’s end; the interaction of the atoms of a diatomic molecule was used to illustrate conservation of energy and the potential-energy curve; quantization of charge was taken up early in the discussion of electricity; considerable emphasis was given to the electric and magnetic fields and the idea of field in general; the nuclear model of the atom was introduced in the chapter on Gauss’s law; the atomic view of resistivity was presented in the chapter on current and resistance; nuclear magnet-

ism was taken up in the chapter on the magnetic properties of matter. And on it went.

Some closing thoughts

This integration of modern topics into the traditional syllabus significantly contributed to the success of the H&R books. Teachers familiar with the standard syllabus could adopt H&R and then choose whether to emphasize the modern parts. The higher level of mathematical demands resonated with the post-Sputnik, cold war call to duty and with America’s great lunar adventure. Learning physics and engineering would strengthen America by strengthening the character and capabilities of America’s youth. We would get to the Moon; we would show the Soviets. However, Federal budget reductions followed the successful American trips to the Moon and the unsuccessful American trips to Vietnam. It became clear that America’s needs for engineers and physicists were limited. The wave crashed on the beach and ebbed.

We still have some captive audiences—premedical and

“... and they still don’t get it ...”

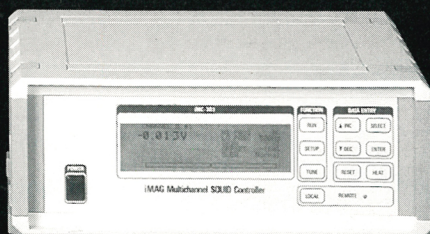
In 1907, William S. Franklin and Barry McNutt were complaining about the lack of skills in their students in ways that seem very familiar today ...

‘A boatman sits on a seat, braces his feet against a cleat and pulls on an oar. What forces act on the boatman’s body?’

The earth pulls on the boatman, the seat pushes on the boatman, the cleat pushes on the boatman and the oar pulls on the boatman. This is all very simple to one who has acquired the habit of analytical thinking but a large group of sophomore engineering students got an average of 45% in their answers to the question after two weeks of insistent coaching on the *fundamental notion of force action*, and nearly every human aspect of boating was represented in the answers, including even the chance of a ducking, for several of the young men would have it that the *water* pushes on the boatman’s body. (From ref. 11.)

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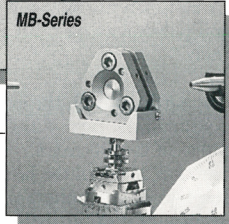
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engineering students—and we still have students excited by the prospects of acquiring a deep understanding of matter and nature. But a large portion of our students must now be persuaded and enticed to take physics, a situation strange to those who enjoyed the heady years of the 1950s and 1960s, but one that is more normal in America's history. Initiation into the wonders of technology and the wonders of the cosmos still allure, but there is also the idea that the very pleasure of understanding the great ideas of physics should attract students. Unfortunately there is a lot of evidence that physics education has not been very good at eliciting this understanding, at enabling students to have the pleasure of comprehension. There is a concentrated effort by some physics educators to better understand understanding itself. There is also widespread pedagogical experimentation in the classroom, in the teaching laboratory and with textbooks—some based on innovative and imaginative uses of instructional technology, some of a more conventional sort—with the goal of making physics more attractive by making it more intelligible.

If Ganot were to return today, he would be fairly amazed by what the introductory physics text has become, but he would still recognize its basic form and structure. Given the rapid evolution of computer media and the World Wide Web, I think it is safe to say that, if he were to return a hundred years from now, he would find the introductory physics textbook changed out of all recognition from what we have known over the past century. On the other hand, I also think that he would find the pedagogical issues very familiar. In 2099, physics professors will still be arguing over mathematical level, over depth versus coverage, over the content of the syllabus, over pace, over the amount of real-world versus simulated experience, over what constitutes understanding and how you measure it. But, for Ganot, at least we would not have to translate "*Plus ça change, plus c'est la même chose.*"

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