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The following review is the second in a series of three that discuss new textbooks for calculus-based introductory physics. A review of Physics for Scientists and Engineers by Randall D. Knight was published in the February issue; a review of Matter and Interactions by Ruth Chabay and Bruce Sherwood will be published in an upcoming issue.

Post-Use Review. Six Ideas That Shaped Physics (second edition, six volumes). Thomas A. Moore. 1846 pp. McGraw-Hill, New York, 2003. Price: $182.58 (paper) ISBN 0-07-256482-2. (Thomas J. Bernatowicz, Reviewer.)

Thomas Moore's *Six Ideas That Shaped Physics* is one of several recent textbooks designed to provide a modern, calculus-based introduction to the study of physics. That goal is brilliantly attained. Rather than attempt to survey all of physics or to function as an elementary reference work, *Six Ideas* introduces students to the modern study of physics by thoroughly developing its major themes, at the same time training students to think like physicists as they deal with realistic, messy problems. Moore's strategies for achieving these goals rely heavily on interactive learning techniques that are used extensively in language and literature classes, but seldom in science classes. Although *Six Ideas* is very well suited for self-study, its adoption in the classroom requires unconventional methods of both study and teaching in order to take advantage of its unique content and structure.

It is thus necessary to evaluate *Six Ideas* as part of a larger strategy for teaching physics. Moore seems to have arrived at his methods by paying attention to education research and to the psychological aspects of learning physics, as well as by taking an aggressive experimental approach towards designing effective classroom experiences. His Instructor's Manual contains a thoughtful 70-page exposition of his successes and failures in the development of *Six Ideas*. One cannot help but admire his willingness to let the results, rather than a specific education philosophy, determine which methods work best. Despite my having taught an advanced section of traditional introductory physics for several years, and despite my natural aversion to anarchic elements in the classroom, Moore's empiricism motivated me last year to try out *Six Ideas* on my own students. The 63 of them (consisting of about equal numbers of natural science, engineering, and pre-med majors, many of whom had taken advanced placement physics in high school), as well as their professor, found the course challenging, interesting, and fun.

Six Ideas consists of six volumes or "units," each dealing with a central theme in modern physics. Any subject not contributing to the direct development of that particular theme is either set aside entirely or relegated to the end-of-chapter problems. This gives *Six Ideas* an overall concept density that is lower than that of its competitors, permitting greater depth and development of each theme. I doubt that there are any physics instructors who would not object that some sacred, indispensable topic has been left out, but that's the price necessarily paid for the streamlined clarity of presentation (and in any event, such unpleasant choices are inevitable even in traditional courses).

The six-unit structure makes the text convenient to use in either a semester- or quarter-based academic year.

Unit C (on conservation laws) introduces the study of physics with a careful exploration of momentum, energy (in all of its physical and chemical forms), and angular momentum conservation. Moore considers these topics to be less demanding mathematically than the usual introduction centered on Newton's laws. They also provide the core unifying concepts for all of the subsequent units.

Moore addresses most of the traditional mechanics topics in *Unit N* (on Newtonian mechanics), but even here his treatment is far from ordinary. On the one hand, he gives minimal coverage of mechanical oscillations (e.g., no treatment of forced or damped oscillations), while on the other hand he tackles head-on some difficult issues that other texts typically minimize. For example, in addition to studying idealized projectile motion, students also tackle projectile motion with realistic drag forces, using software called (what else?) NEWTON that they download from the *Six Ideas* website (www.physics.pomona.edu/sixideas/). *Unit N* ends with a detailed exploration of the pinnacle of Newtonian physics—the analysis of planetary motion—but here also NEWTON (the software) permits students to deal quantitatively with hyperbolic and elliptical orbits, not just circular ones.

Given that some traditional mainstays of introductory physics curricula like fluids and geometrical optics have been jettisoned, it may seem bizarre that Moore spends the equivalent of one-third of a semester on special relativity, and devotes a separate *Unit R* to it. His rationale is that special relativity gives students the chance to see a complete development of one topic in theoretical physics without the usual, difficult mathematical appurtenances. *Unit R* is a masterpiece of pedagogy. Its language is precise and clear, its methodology thorough and modern. Students get extensive experience in the use of space-time diagrams, coordinate transformations, and four-momentum. My own students were so delighted by this unit that some even read ahead (!).

Unit E (on electromagnetism) seamlessly incorporates special relativity into the development of the subject, so that students see early in their physics training the deep inherent symmetries—how one reference frame's electric field may be another's magnetic field. Circuits are de-emphasized in favor of making the treatment of waves and vector fields more robust. Although Moore's handling of the technical aspects of the subject is very good, my students opined that the organization was not particularly effective and that the subject development in *Unit E* was the least well motivated of the six units. Moore agrees. For the upcoming third edition, he has completely restructured *Unit E* and replaced the integral forms of Maxwell's equations with the conceptually more straightforward differential forms, in part to facilitate the transition to the wave equation as well as to underscore the concept of local field equations.

Unit Q (on quantum physics) accomplishes a lot within comparatively few pages. Moore bravely takes a Feynman-like approach to introducing quantum concepts, using spin analyzed with Stern–Gerlach devices as a prototype of quantum behavior, as well as thoroughly dissecting the two-slit problem. Difficulties are not dumbed down, but embraced and finessed to yield important insights into quantum behavior. He also gives a meaty introduction to the Schrödinger equation and energy eigenfunctions. Students learn how to sketch wave functions for a variety of potentials, and custom SCHROSOLVER software produces quantitative numerical solutions that likewise help to hone students' mathematical intuition. Several chapters each on atomic and nuclear physics round out the subject.

Like *Unit Q*, the final and shortest volume, *Unit T* (for thermal and statistical physics), uses a distinctly innovative approach. After introductory chapters on temperature, thermodynamics, and the microscopic behavior of gases, students are initiated into the world of microstates and macrostates, entropy and irreversibility, the Boltzmann factor, and the Maxwell–Boltzmann distribution. A very interesting and effective device is the use of the Einstein solid as a simple prototype of quantum statistical behavior. The payoff comes when the mysterious temperature dependence of heat capacity is elucidated. Throughout *Unit T*, conceptual underpinnings are reinforced by helpful, quantitative software. As is true for all of his software, no programming effort on the part of the students is required. Rather, exploration of the effects of varying the program input is encouraged, without students becoming bogged down in programming details.

Textbook study is at the core of Moore's approach, so the unit chapters have a consistent and transparent structure that enhances readability. The chapters are short enough that one can be covered completely every class meeting. Each chapter deals with relatively few topics that are closely linked through the narrative, conveying an impression of a well-guided tour that arrives inevitably at its destination. A "visitor's guide" to this tour is given at the beginning of each chapter in the form of a two-page overview that briefly discusses the content and main lines of reasoning of each section. Every key equation is highlighted in a box that defines the symbols used, discusses the purpose of the equation, and points out any caveats regarding its use. These chapter overviews are not only summaries, but are also readable guides that serve as a motivation for the ideas presented, preemptively addressing students' inevitable questions about why one is going in this particular direction. The chapter prose is lively and informal, conveying in a frankly professorial tone that is tinged at times with humor and irony, the satisfaction of proof and the joy of observation and discovery. Self-study exercises embedded in the text serve to advance the treatment, test one's understanding, or help clarify misconceptions. Moore gives complete and detailed answers to these exercises at the end of each chapter, in case the reader gets stuck.

Moore believes that technique is crucial in solving physics problems and that practice is essential. He addresses the former by taking a consistent four-component approach to problem solving in his chapter examples. This may be described roughly as (1) translating the problem using words and/or diagrams; then (2) forming a conceptual model in terms of equations that clearly indicate any assumptions, and known and unknown quantities; then (3) solving the equations; and finally (4) evaluating the result in terms of sign, magnitude, units, etc. He addresses the question of practice by providing four distinct classes of problems. The "basic" or B problems are ones that can be solved typically by using a single equation, and tend to be the kind to which students who have had high school physics are already accustomed. However, his "synthetic" or S problems require a synthesis of related concepts, and are not generally amenable to the much-deplored habit of skimming the textbook to find the perfect equation(s) that will accommodate all of the "knowns." The "rich content" R problems are typically the most fun for both the instructor and students. They tend to be interestingly realistic, and to require assumptions and data that are not always given. My own experience is that R problems (and many of the S problems) tend to evoke ample discussion among the students, who are driven by curiosity to find an answer. They also found solving these problems to be empowering, because they illustrate how grand conclusions can often be drawn from a synthesis of basic observations, calculation, and physical reasoning. For example, in the sixth chapter of *Unit T* students are challenged to calculate the ratio of protons to neutrons a hundredth of a second after the Big Bang, and to "discover" the 3-K cosmic background radiation. The "advanced" A problems tend to be sophisticated mathematically, and attain their greatest use in providing the instructor with examples that further develop the topics in the chapters.

Obviously, no matter how excellent the text, it is useless if it is not read. To motivate students to read the text and think about the chapter topics, I assign two problems from each chapter that are due on the day that the chapter is discussed in class. In addition, I assign three more problems per week (one from each chapter covered) that are due at the beginning of the next week. After receiving an initial grade for a problem, the students can revise their answers with reference to Moore's thorough solutions, and resubmit them for additional credit. This procedure is very successful in inducing students to confront their errors and increase their understanding by rewarding them for their effort. Somewhat surprisingly, no one complains about the work load. Students tend to think that the daily homework assignments keep them on task and greatly reduce the time (and anxiety) spent in preparing for exams. One student wrote in the course evaluation that "…since we had such a deep understanding of each topic, applying our knowledge to any practical problem presented in the test was easy."

The active learning aspect of *Six Ideas* is greatly facilitated by the "Two-Minute Problems" at the end of each chapter, which consist of multiple-choice and true/false exercises designed for in-class participation. In my own, large lecture hall class, I have these printed on overhead transparencies to provide a focal point for discussion. At the beginning of the semester the students, in impromptu fashion, form their own nearest-neighbor, two- to four-member groups in which they discuss the two-minute problems. At the end of the two minutes, a group representative points to one of the large letters provided on the back of the unit textbook, indicating the group consensus. I then take note of the answers, and have volunteers explain the reasoning behind their choice. Often this leads to constructive discussion as other students object to an explanation or offer an alternative one. The students are uniformly enthusiastic about the two-minute problems, since they obviously alleviate boredom, provide a convenient venue for questions (and talking in general), and present an opportunity to find out how others have thought about the physics.

How does a *Six Ideas* class differ from the standard, lecture-based course in introductory physics? The most important difference is that the instructor's role is more that of a coach than a sage. Beyond that, the nature of the class really depends on the instructor's stylistic choices, as well as on the physical classroom environment. Clearly, a class of 80 students in a lecture hall will operate differently than a class of ten in a small classroom. My typical class meeting consists of a mixture of interchangeable components, the duration of each having been very carefully estimated beforehand to make optimal use of class time. I use two-minute problems, example problems drawn from the end-of-chapter exercises, demonstrations, and "mini-lectures" (of no more than 10–15 min each) that tend to illustrate connections between various topics, to provide alternative derivations, or to extend the physics to subjects beyond those discussed in the textbook. Strange to say, a successful *Six Ideas* class meeting with its apparently "loose" structure really requires an extraordinary amount of organization and preparation on the part of the instructor. An example of the happiest teaching circumstance occurs when a two-minute problem generates a divergence of opinion that can be resolved by a simple experiment or demonstration. The insight generated may then be exploited either by solving a related problem or by increasing the sophistication and scope of the initial question.

At first glance, it may seem that all of this interaction would lead to a superficial treatment of topics compared to a standard lecture-based format, because of the necessary minimization of lecture time. This is not so. It is instead a very effective and very efficient procedure overall. Because of the text reading and problem solving done prior to the class meeting, the students are already well acquainted with the topic *du jour* before they come to class, and their minds are prepared to augment and deepen an initial understanding by exposure to and participation in the various classroom activities.

How well does the *Six Ideas* program work? Based on student feedback and performance, it worked very well indeed. The course evaluations were very positive overall, and students generally felt that they learned more physics, while having a great deal of more fun and less anxiety doing it, than their peers in the traditional, lecture-based introductory physics course. Ultimately, the students tend to be the best judges of the amount and quality of their learning. Of this experience, the opinion of one freshman student is worth noting: "I feel as though I have gained a great deal of knowledge of not only equations or problems, but of the actual techniques and thought patterns of a physicist." As for me, I am now well into my second year of *Six Ideas* (with even more students this time), and I have no intention of looking back.

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Science and Ultimate Reality: Quantum Theory, Cosmology and Complexity. Edited by John D. Barrow, Paul C. W. Davies, and Charles L. Harper, Jr. 742 pp. Cambridge U.P., Cambridge, 2004. Price: $75.00 (cloth) ISBN 0-521-83113-X. (David Shortt, Reviewer.)

In March 2002, to honor John Archibald Wheeler's 90th birthday year, a group of researchers gathered near Princeton University for a symposium dedicated to exploring new approaches to difficult problems in the fields of quantum mechanics, cosmology, and information science—areas to which Wheeler has made many contributions over a long and distinguished career. One of the results of the symposium is *Science and Ultimate Reality: Quantum Theory, Cosmology and Complexity*, a well-organized survey of some of the boundaries of modern science.

A short list of Wheeler's achievements ranges across large swaths of 20th-century physics. He studied with Niels Bohr in the late 1930s and developed the theory of nuclear fission, he developed action-at-a-distance electrodynamics with Richard Feynman (whose Ph.D. thesis he supervised), and he resurrected from obscurity the study of black holes, a term he coined, in the 1950s and 1960s. Wheeler studied the quantum measurement problem and developed the idea of a "participatory universe" in the 1970s and 1980s, and he coauthored classic textbooks on special and general relativity. Perhaps most importantly, this worthwhile volume is a demonstration that Wheeler has inspired several generations of scientists with his keen insights and courage to ask really big questions such as "How come the quantum?" "How come existence?" and "It from bit?"

The book's strength, and perhaps also its weakness, is the breadth of material covered. The reader will find discussions of quantum field theory as well as consciousness. There is even a philosophical comparison of Wheeler with the Greek thinker Heraclitus. Readers curious about the foundations of quantum mechanics, the measurement problem, decoherence, inflation, quantum gravity, quantum computing, or