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Reviewing a physical-science book for grade 8 or 9

Force, Motion, and Energy

2002. 150 pages. ISBN: 1-882057-12-0. Science Curriculum Inc., 24 Stone Road, Belmont, Massachusetts 02478.

Fine Scientific Insight, Masterful Pedagogy, Interesting Writing

Lawrence S. Lerner

It has been a long time, and a lot of textbooks ago, since I was an eighth- or ninth-grader, yet I have found *Force, Motion, and Energy* stimulating to read. Published by Science Curriculum Inc. (SCI), this wonderful book displays fine scientific insight, masterful pedagogy and interesting writing as it sets forth standard subject matter dealing with mechanics and heat. The sequence of topics is unorthodox, but the handling of those topics is almost impeccable -- logically, experimentally, and pedagogically. Moreover, I have not detected so much as one typographical error in the entire book.

Perhaps I should not be surprised to find that this book is so good, since the five authors of *Force, Motion, and Energy* include Uri Haber-Schaim, Reed Cutting, H. Graden Kirksey and Harold A. Pratt [see note 1, below]. These four created the superb textbook *Introductory Physical Science,* which SCI published in 1999 [note 2].

Like *Introductory Physical Science,* the present book is solidly founded on a fine collection of experiments for students to carry out. *Force, Motion, and Energy* can serve by itself in a one-semester course, or it can be used with *Introductory Physical Science* in a cogent one-year sequence.

The *Teacher's Guide* accompanying *Force, Motion, and Energy* is well written and useful. In particular, it is diligent in pointing out difficulties that students may encounter in doing some of the experiments, and is very helpful in explaining how the teacher and the student can deal with those difficulties.

An Elegant Series of Experiments

Force, Motion, and Energy begins with a careful exposition of the physical meaning of "force," based on experiments that the student performs with a spring scale. The ideas of proportionality and the proportionality constant are introduced immediately and are illustrated by Hooke's law. Next, the authors provide a careful and clear exposition of the concept of a unit, using the newton as an example. This is followed by a series of experiments with a pair of permanent magnets: The student finds that not all forces are directly proportional to displacement, and that some forces can act at a distance.

In an elegant series of experiments on sliding friction, SCI's authors expand the concept of the proportionality constant (now exemplified by the coefficient of friction). Then, in an ingenious extension of the earlier procedures in which the student used a spring scale, the authors present an experiment involving two such scales and a block mounted on a cart: The student uses the spring scales to exert a force on the block and an opposing force on the cart, and the student thus "discovers" Newton's third law. This approach is notable because it completely avoids a common source of confusion: On which bodies are the action force and the reaction force acting?

In chapter 2 the authors set out the concepts of weight, mass, volume, and density. Then, building upon their earlier discussion of proportionality, they elucidate pressure as the ratio of force to area. Pascal's law is introduced experimentally, as is Archimedes's principle.

In chapter 3, the authors introduce the vector. They elegantly put forth the parallelogram rule, and they show how the geometric addition of vectors allows us to understand such important systems as inclined planes. The student who masters this material will be thoroughly prepared to deal with the trigonometric addition of vectors at a later time.

Similarly, a sequence of qualitative experiments with air pucks provides insight into the relation between force and acceleration, paving the way for a formal, quantitative study of Newton's second law in a later course.

Chapter 4 covers distance, time, speed, and the equations that relate them. Chapter 5 deals with wave motion, emphasizing the important distinctions between the kinematics of waves and the kinematics of particles, and the student learns how the time lapse between *S* and *P* waves can be used to determine the distance to an earthquake source.

Chapter 6 ("Heating and Cooling") and chapter 7 ("Potential Energy and Kinetic Energy") are, to my mind, the cleverest in the book. At the beginning of chapter 6 the authors make clear that temperature changes can result from a wide variety of dissimilar events. They introduce the concept of thermal energy, discuss changes in thermal energy, and provide calorimetric experiments that point to specific heat capacity, heat of fusion, and the joule.

In chapter 7 the student employs some modifications of Joule's mechanical-equivalent-of-heat experiment to explore connections between thermal energy and gravitational potential energy, between thermal energy and elastic potential energy, and between thermal energy and kinetic energy. This work enables the authors to define energy quantitatively and with some rigor; I never before have seen this in a textbook for students at this level.

The book ends, somewhat abruptly, with an exposition of the law of conservation of energy, including a passage that hints at the second law of thermodynamics:

No process has even been observed in which the law of conservation of energy has been violated. However, not every process that satisfies the law will necessarily take place. Think of Experiment 6.2, Mixing Warm and Cool Water. We defined the cooling of the warm water as a loss of thermal energy so that the loss equaled the gain of thermal energy by the cool water. Imagine the opposite process. A quantity of water at some uniform temperature inside an insulated container separates by itself into two parts, one warmer and one cooler. This process never happens, although it would not violate the law of conservation of energy. . . . The law of conservation of energy tells us what is not possible. However, it is not sufficient to tell us what is possible. [page 131]

Some Suggestions for Improvements

Having praised this admirable book, I now should note some of its features that can be improved when the next edition is prepared:

- In the first section of chapter 1 we read: "What if you push or pull on something and it does not move? Something must be pushing or pulling just as hard in the opposite direction." For most students, this is counterintuitive. It will be useful to tell the student that this issue will be addressed later in the book.
- The caption for figure 1.2 refers to a zero mark, but no such mark is visible in the figure.
- From the very beginning of the book, the authors make use of important mathematical concepts that include graphs, ratios, and proportionality constants. There is a short exposition of these concepts in Appendix 2, but I suspect it is too brief, and comes too late, to meet the needs of many students (and the needs of some teachers). The authors should teach these ideas in the main text, rather than relegating them to an appendix [note 3].
- On page 12, a nice experiment demonstrates that the frictional force between a block and the surface on which the block rests does not change when the block is turned so that a smaller area of the block makes contact with the supporting surface. But the conclusion to which the student is led -- that in cases of dry-contact friction, the frictional force is independent of the area of contact -- is true only in the macroscopic sense. At the microscopic level, the extent of contact between the block and the surface does not vary much, regardless of whether the macroscopic area of contact is large or small. The authors mislead the student again as they ask this follow-up question: "Would letting a little air out of the tires of the family car increase the car's traction on an icy road?" The expected answer is *no,* but the right answer is *yes.* The case of a tire on an icy road is much more complicated than a case of dry-contact friction. Reducing the pressure in a tire, thus increasing the area of contact between the tire and the road, can indeed improve traction.

- On page 19, in question 20c, the authors ask why electromagnets are preferable to permanent magnets for moving scrap metal around. The desired (and obvious) answer is that electromagnets can be turned on and off at will. Yes, but there is another important reason: An electromagnet is much less costly and much less bulky than an equivalent permanent magnet. The student has not been equipped to deal with this point.
- The consideration of weight and mass, on page 22, can be made clearer. The authors begin by pointing out that the weight of an object changes as it is moved within a building, though the change is not large enough to be detected by ordinary instruments. But the discussion then shifts abruptly to the difference between a brick's weight on Earth and the same brick's weight on the Moon -- which serves only to confuse the issue. Then the discussion shifts to the idea that a brick's weight varies from place to place on Earth, and a nearby table gives the weight of a hypothetical brick in New York, in Denver, in La Paz, and at the top of Mt. Everest. I am sure that measurements of *g* have actually been made at the first three locations -- but the fourth? I have my doubts. Finally, the equal-arm balance is introduced as a method of directly comparing masses rather than weights. But in fact, such a balance does compare weights; its virtue is that it is unaffected by local variations in *g* [note 4].
- On page 23 the standard kilogram is described as "a platinum cylinder kept under special conditions near Paris, France." What are these special conditions? If they are not to be explained, mentioning them serves only to mystify the reader.
- On page 25, the authors start their presentation of a problem by writing: "Suppose a bottle of water for a water cooler weighs 360.00 N in New York City." This is an unrealistic value. Let us say that the bottle holds 10 gallons of water (though 5-gallon bottles are more common). The weight of the water alone would be about 83 lb, or about 370 N, and the weight of the bottle would have to be negative!
- On page 29, the student sees two photographs and reads this description of what they depict: "Figures 2.6 and 2.7 show another example in which force per unit area -- not simply force alone -- is important. A very thin wire and a string, each loaded on both ends with weights, were draped over a block of ice at the same time. The weights hanging from the thin wire exerted a total force of 5 N. The total force on the string was 20 N. After about half an hour, the thin wire cut several millimeters into the ice. The string, with four times as much weight on it, was still sitting on the surface of the ice. The force per unit area exerted by the wire was many times greater than the force per unit area exerted by the string." It's undoubtedly true that the wire's deeper penetration into the ice was attributable to the greater pressure that the wire exerted, but a skeptical student may well ask whether the difference was due to the wire's greater thermal conductivity; this demonstration should be replaced by one that uses two wires made of the same material but having different cross sections.

I look forward to seeing all these deficiencies remedied in the next edition. In the meantime, I recommend *Force, Motion, and Energy* in the strongest terms possible. I wish that I had had its like when I was an eighth-grader!

Notes

1. SCI is an honest company, and the persons who are listed as authors on the title page of an SCI book are really the book's authors. This is unusual. In typical books sold by the major schoolbook companies, the lists of so-called authors are fictitious and have been concocted to serve as sales-promotion features. For an examination of how fake lists of "authors" were invented and juggled in successive versions of a physical-science text issued by Glencoe/McGraw-Hill, see my review "Next Time, Glencoe Should Try to Get Some Real Authors" in *The Textbook Letter,* Vol. 8, No. 1.
2. See my review "This Book Is the Best, by a Wide Margin" in *TTL,* Vol. 10, No. 4.
3. The authors seem to know that their handling of basic mathematical ideas leaves room for improvement. In their *Teacher's Guide,* in a passage dealing with material in chapter 6 of the textbook, they tell the teacher this: "The mathematical reasoning in this section will very likely be difficult for your students unless they have a good mathematical background in proportions." If this is the case for material chapter 6, it must be the case, *a fortiori,* for material in chapter 1.
4. For many years, A.A. Michelson showed to visitors an equal-arm balance that he had set up in Ryerson Physical Laboratory at the University of Chicago. The pan on one arm was located on the third floor of the building while the pan on the other arm was suspended by a much longer linkage and was located in the basement. Michelson could readily show that this instrument was balanced only when the masses in the two pans were (slightly) unequal.

Lawrence S. Lerner is a professor emeritus in the College of Natural Sciences and Mathematics at California State University, Long Beach. His specialties are condensed-matter physics, the history of science, and science education. His university text *Physics for Scientists and Engineers* was issued in 1996 by Jones and Bartlett Publishers, Inc. (Sudbury, Massachusetts).

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