a body also has angular momentum, that is the aggregate of the angular momentum of each of the particles composing the body. I hope that those interested in improving physics education in high schools get their physics straight.

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The article "Advanced Physics in the High Schools," although it raises some interesting truths, has also created apparent paradoxes. Those of us who have taught both of the Advanced Placement Physics courses in high school can testify that the AP Physics B course is the more difficult of the two to teach. Here we arrive at the first paradox. The AP Physics C course covers only two of the five big areas of introductory physics—mechanics and electromagnetism. The B course also includes thermodynamics and fluids, waves and optics, and modern physics. A score of 5 on the B exam is much more praiseworthy than a 5 on the C exam. Yet the broader, more comprehensive exam gets less respect from universities and colleges.

The National Research Council implies that the AP Physics B course is too broad to be stimulating. However, many AP physics teachers have observed that the B course produces more physics majors than the narrower C course. Many of my former students who went on to declare physics as a major said that physics offered more variety than other sciences. The NRC says that "stimulating interest . . should be a key goal," yet it wishes to abolish the course that has motivated more potential physics majors than any other high-school course I offer.

The second paradox concerns the time spent on topics. If done correctly, both AP physics courses should be second-year courses for all but the top 5% of high-school students. For most of my students, getting a 5 on either exam was a result of 360 classroom hours. According to the NRC, teachers do not have enough time to completely develop conceptual understanding, inquiry-based learning, and problem-solving skills for the material on the AP Physics B exam. Colleges and universities across the nation, however, have a similar curriculum, use the same books, yet claim to be able to accomplish these learning objectives in 90 hours over two semesters. Why does the NRC question the group that spends 180 or 360 classroom hours on the material instead of the group that spends only 90 contact hours?

The third paradox has to do with a statement from the article. On the one hand, the authors say that, as teachers, they "have found that students at all levels like intellectual challenges that are within their reach." And on the other hand, the NRC wants to disband both AP physics courses in favor of one course focused around "a single version of Newtonian mechanics." How can the more limited course challenge a diverse group of high-school students "at all levels"?

A small amount of the article addresses the only real problem with the AP Physics C course: waiting on the students to get to integral calculus. At that point, the AP Physics C course becomes an asset. Instead of mathematics being used to understand physics, the reverse usually occurs. As the science teacher in a team, I can show how summations lead to integrals without losing continuity in either AP course, Physics C, or Calculus. The NRC acknowledges that problem solving is important and emphasizes collaborative learning. Yet it recommends isolating physics from the rest of the non-science high-school curriculum. In my opinion, this last is the saddest contradiction of all.

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GOLLUB AND SPITAL REPLY: We appreciate the thoughtful letters our article has stimulated. The Physics Panel Report of the NRC study explicitly recommends an introductory course prior to AP, and we agree with Art Hobson on the importance of teaching concepts in depth, not only before AP, but also as part of it. Students often do not have time for two physics courses in their program. Currently, the problem is much more serious in physics than in chemistry, which typically comes earlier. What will happen if "physics first" catches on? Some schools are now teaching conceptual physics in the ninth grade, followed by an optional AP course in the junior or senior year. That approach seems promising.

Michael Wood sees the AP program as fundamentally wrong. We point out many problems, but our assessment is that the AP program makes positive contributions to serious science study in many schools. The NRC report includes specific recommendations for improving the AP curriculum and exams. Requiring the exams might well be problematic because of the cost. Some states, by subsidizing exam costs, make the exams more widely and equitably available.

Still, we are not advocating AP as the only or best option for advanced study in physics or the other sciences. The full NRC report has an extensive discussion of the International Baccalaureate program, and other approaches are treated briefly. Also, implementation of the present AP program varies widely from school to school. The AP "syllabus" that Wood mentions is actually little more than an outline. Many AP teachers do in fact design their own courses.

The panel recommended that "formal calculus should not be required" for the new standardized mechanics. Woods perhaps misinterpreted that recommendation to imply that no calculus should be used in the entire program. That was not the intention. It is certainly not true that dropping the calculus requirement would reduce mechanics to memorized equations. An excellent understanding of elementary mechanics can be achieved by students who have a solid grasp of algebra and the concepts of limiting slopes and areas.

Many experienced high-school teachers have found that complex calculations monopolize students' attention at the expense of central organizing ideas like conservation of energy. We also need to be concerned about equitable access to advanced study. In many schools, calculus comes late, and not all students take it. Our advice, if implemented, would somewhat raise the mathematical level for those currently taking AP Physics B, and would maintain the accessibility of advanced mechanics study to a wide variety of students. We stress that the panel makes this recommendation for *mechanics only* and expects that formal calculus will continue to play a central role in the advanced study of electricity and magnetism.

Greg Jacobs properly emphasizes the pressure that teachers receive from students and parents. The NRC committee and panels included many teachers, so we are, of course, aware of this pressure. However, even if the courses are redesigned with less emphasis on the precise replication

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of college courses, they will continue to be important for documenting students' ability to handle challenging college-level material, and will therefore continue to favorably affect admissions. Although that positive impact can continue to be used for motivation, we think that the best way to motivate students is to increase their success in learning rather than to try to convince them that the distasteful medicine of AP physics will be beneficial.

Marcelo Alonso detected a typographical error, for which we apologize. The College Board publication refers to "circular motion," not "circular momentum."

We strongly disagree with many of Robert Mullins's assertions. The NRC panel did not criticize the AP Physics B course as being "too broad to be stimulating," but rather too broad to allow learning in depth. However, if the B course is taught in two years, as some schools are doing, it is quite a reasonable curriculum. We agree that the problem of breadth versus depth also exists in college courses, and the NRC report points out that colleges also need to be more realistic. Oddly enough, the complete AP Physics-B program is more compressed than many college courses, in which instructors often choose to omit topics.

The NRC panel certainly did not recommend "isolating physics from the rest of the nonscience high-school curriculum." In fact, the report recommends increasing attention to interdisciplinary opportunities.

Although mechanics provides abundant intellectual challenge, the Physics Panel agrees with Mullins that the study of other topics should also be available to advanced physics students. Ordinarily, the common mechanics unit we propose would be covered in one semester; that would leave the second semester free for topics like electricity and magnetism or modern physics. Although students are excited by exposure to the forefront of physics, we should not underestimate the satisfaction they can derive from mastering mechanics: It is close to their everyday experience, and even mechanics contains challenging surprises—chaos, for example. Too many students are lost at an early stage. Because few students place out of a full year of physics at present, an agreed standard for mechanics could at least allow a larger number of students to omit the first semester of college physics.

The full NRC document and the Physics Panel's report are available online at http://www.nap.edu/catalog/10129.html.

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Fermi Tales

A quote from Hans Bethe's article (PHYSICS TODAY, June 2002, page 28) about Enrico Fermi is especially indicative of Fermi's personality and sets a desirable standard for anyone: "Fermi was always willing to help with specific problems; anyone could come to him." As a graduate student working at Los Alamos during the summer of 1953, I had a problem that required both a theoretical and an experimental approach, and I needed help. A resident physicist remarked, "Take it to Dr. Fermi," whose office was just down the hall from me in the old Gamma Building. With hesitation and apprehension, I did so. I walked out later with a new friend and temporary mentor, and with suggestions that led to a technical solution.

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The table on page 41 of the June 2002 issue of PHYSICS TODAY lists the courses that Enrico Fermi taught at the University of Chicago. However, it omits his last course, Quantum Mechanics (Physics 341–342), which he taught in the winter and spring of 1954. I still have my set of Fermi's mimeographed handwritten notes that Valentine Telegdi mentions. Those notes were later published as *Notes on Quantum Mechanics* by the University of Chicago Press in 1961, with a second edition in 1995.

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Correction

August 2002, page 59—In the first item, "Spectral Confocal Microscope," TCS SP2 AOPS should be TCS SP2 AOBS. ■