curriculum that is not based on introductory college courses. However, the authors neglect what I consider the most useful aspect of the AP program: the perceived authority of courses that replicate college-level work.

Those who are not directly involved with high-school politics tend to underestimate the pressure teachers receive from students and parents. Many students have earned top marks in all their classes, including math and science, through middle school and early high school simply by, in Gollub and Spital's words, "rote memorization of facts or equations, or following narrowly prescribed instructions." Many physics students become shocked and angry at the beginning of the school year when that approach does not lead to success in physics. Only the rare, ideal student decides for himself that such disillusionment necessitates a reevaluation of his approach rather than a complaint about the teacher's unfairness and unrealistic expectations. High-school physics teachers who face such complaints are often placed at a further disadvantage because most administrators have no understanding of the content or goals of the physics course. The path of least resistance is thus to water down the course so that the "rote" learners can earn an A.

Students and parents do not usually see the cause-and-effect relationship as "learn a lot, develop intellectual prowess, earn admission to college." Instead, they understand "get As, get into college." It is the grade, not the course content, that motivates most students. Students often develop an adversarial relationship with a physics teacher because they perceive that the teacher is "making" them work too hard. In their mind, the less depth of material, the more likely an A becomes. The teacher is perceived as bad for requiring any depth of thought.

With the AP curriculum replicating a college course, though, the tables are turned. A teacher of an AP course can answer those "you're too tough" complaints in a language the students understand: "If you want to get Advanced Placement and do well in college, you must trust me and learn the skills I ask you to learn."

Using college admission as a motivation tool is a temporary thing, to be used in that difficult first month of the school year. I find that, by December, such artificial motivation is unnecessary. Once students finally adapt themselves to the study habits and thought processes required for success in physics, the course can drive itself. High-school students are eager and willing to learn physics for its own sake, once they recognize the intellectual beauty of the subject. For teacher and students to get to December, though, the perceived authority of a non-negotiable college-level course is a practical necessity.

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I was surprised that, in the article on advanced physics in high schools, the expression *circular* momentum and rotation appears in the table on page 51 in item E under "Newtonian mechanics." The correct term is *angular* momentum, which is related to the general motion of a particle. Angular momentum is not necessarily circular and is certainly not a rotation. Even a particle with rectilinear motion has angular momentum relative to any point not on its path. Although the rotation of 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

*continued on page 82*