Learning and Understanding: Improving Advanced Study of Mathematics and Science in U.S. High Schools: Report of the Content Panel for Physics

Committee on Programs for Advanced Study of Mathematics and Science in American High Schools, National Research Council

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THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Content Panel Report:

Physics

1

Introduction

The National Research Council's Committee on Programs for Advanced Study of Mathematics and Science in American High Schools (parent committee) formed a physics panel to provide advice on the effectiveness of and potential improvements to programs for the advanced study of physics in American high schools. Appendix A presents the parent committee's charge to the panel. The physics panel met twice (in May and July 2000) to address its charge from the parent committee. The panel was chaired by a member of the parent committee, who served as liaison to the committee and consolidated the panel's findings and recommendations into this report. Panel members included experienced college and university physics professors noted for their work in physics education, as well as high school physics teachers (for biographical sketches, see Appendix B).

To develop a framework for its recommendations, the panel began with a thorough discussion of recommended practices that it would expect to find in a good advanced high school physics program. Chapter 2 presents a summary of the panel's review. Using the model that emerged from that discussion, the panel evaluated the two dominant advanced high school programs—Advanced Placement (AP) and International Baccalaureate (IB)—to determine the extent to which they encourage the use of those recommended practices in their physics courses. The results of this evaluation are presented in Chapter 3, along with the panel's recommendations for improvements to both programs.

Although the panel lacked sufficient time to consider all possible alternatives to the AP and IB programs, it did consider one alternative approach, presented in Chapter 2. The panel recognizes that each high school is a unique environment with its own strengths and limitations. Thus there is unlikely to be a single advanced program that could reasonably be implemented with complete uniformity across the nation. Instead, the panel suggests that high schools and school districts offering advanced physics instruction adopt a program that has the general characteristics described in

Chapter 2 but is flexible enough to be implemented in a school's or district's specific context.

Chapters 4, 5, and 6 examine three topics of importance to the panel's review of advanced study programs in physics: Chapter 4 looks at the crucial role played by teaching and learning; Chapter 5 summarizes changing emphases in physics and their impact on advanced physics instruction; and Chapter 6 addresses the linkage between advanced high school physics programs and college physics programs. Each of these chapters includes the panel's specific recommendations in the respective area. Finally, Chapter 7 summarizes the panel's main findings and overall recommendations.

2

Recommended Practices for Advanced Physics Instruction

WHAT IS AN ADVANCED PHYSICS PROGRAM?

The term “advanced” is taken here to mean study that is substantially beyond the level of the physics required for high school graduation under the *National Science Education Standards* (*NSES*) (National Research Council [NRC], 1996). Although the goal of an Advanced Placement (AP) physics course is to substitute for a physics course that would otherwise be taken in college, that is certainly not the only possible reason for undertaking or offering an advanced program of study in high school. In some cases, traditional high school–level courses are simply not sufficiently challenging to interest the brightest students. In many cases, students undertake advanced study to enhance their college applications. In still other cases, students may be interested in particular areas of physics that are not covered in available high school–level courses (as discussed later in this chapter). Certainly, the particular program adopted by each high school will depend a great deal on exactly what goals that program is intended to meet.

PREREQUISITES FOR AN ADVANCED HIGH SCHOOL PROGRAM

The panel recognizes that the level of preparation of students entering advanced physics programs varies widely from high school to high school. Nevertheless, we believe that there are two fundamental prerequisites most entering students should meet:

- Prior to enrolling in an advanced physics course in high school, students should have studied the physics that is suggested as a requirement for high school graduation in the *NSES* (NRC, 1996). This requirement can be satisfied with the first year of a 2-year physics program. This is the approach adopted by the International Baccalaureate (IB) program (as discussed in

Chapter 3). If a 1-year advanced course is the first time that entering students encounter physics, the usual result is a packed schedule that allows too little time to develop the depth of understanding that is the fundamental goal of the program.[1]

- Students should be fluent in mathematics through the precalculus level (see the discussion below). In particular, by the time they are ready to study advanced physics, students should be skilled in algebraic manipulation and have a firm grasp of basic trigonometry. Emphasis should also be placed on the use of proportions to solve problems, estimation skills, the use of international units, and scientific notation (powers of 10). Acquiring all necessary mathematical skills may well take several years of study before a student enters the advanced physics program. The panel encourages high school physics teachers to work closely with the mathematics departments of their schools to develop the necessary courses of instruction.

Mathematics is the language used to describe the fundamental laws of physics. Just as it is very difficult to teach physics to students who barely understand English (or the language of instruction), it is equally difficult to teach physics to students who do not "speak mathematics." At the level of advanced physics study in high school, speaking mathematics consists primarily of facile manipulation of algebraic equations and an intuitive grasp of the significance of those equations. For example, students should have no doubt that linear relationships lead to straight-line graphs and that the presence of curvature in a graph implies that the relationship cannot be linear.

While knowledge of calculus is unquestionably helpful in the study of advanced physics, it is not absolutely essential. Ideas such as the derivative and integral can be introduced in physics classes by discussing the slope of tangent lines and the area under curves. However, the level of mathematical skill of students may well play a role in the selection of optional physics topics (as discussed later in this chapter).

THE MOST IMPORTANT OBJECTIVES

There was strong consensus within the panel that the most important objectives for advanced study in high school physics are not tied to particular topics in physics. The panel is far more concerned with promoting more general dispositions, abilities, and habits of mind. In particular, advanced study in physics should help students further develop the following:

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[1] The panel acknowledges that there are circumstances under which it is appropriate for students to take advanced physics as a first-year physics course. This may apply to exceptionally talented students or to students in schools where scheduling considerations leave no reasonable alternative. Nevertheless, most students would be well advised to begin their study of physics with a sound high school–level course.

- Excitement, interest, and motivation for further study in physics
- Facility with mathematics as a means of communicating, examining, and refining ideas
- Scientific imagination and creativity
- Scientific habits of mind or the abilities and inclinations:[2]
  - –To look for and examine assumptions hidden in the student's own and others' reasoning
  - –To seek precision and clarity in forming and communicating ideas, including the use of mathematics
  - –To design and conduct empirical investigations to answer scientific questions
  - –To identify and reconcile inconsistencies between the student's understanding and observations
  - –To develop, implement, test, and revise models of physical phenomena
  - –To develop and learn to work within a framework of theoretical principles

DESIGNING A CURRICULUM TO MEET THESE OBJECTIVES

The Central Role of Newtonian Mechanics

Although the objectives listed in the previous section can be met through a thorough study of many different areas of physics, some commonality among programs is clearly desirable, especially when advanced programs serve as substitutes for physics courses in college. Given the central role of Newtonian mechanics in physics, both historically and conceptually, the panel recommends that any advanced study of physics include Newtonian mechanics. Mechanics provides an ideal framework for achieving the objectives cited above. At the same time, familiarity with mechanics is universally expected of students entering college who have completed an advanced high school physics program.

Maximizing the Commonality of Advanced Programs in Newtonian Mechanics

Because the study of Newtonian mechanics serves as the foundation of any good program of advanced physics study, the panel recommends that

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[2] We note that the Theory of Knowledge course included in the IB program (see Chapter 3) deals with the habits of mind listed here. This is an advantage of the IB program; since it is a program rather than a course, one teacher need not do everything.

the set of topics addressed be standardized as much as possible across the nation. While the exact details of such a nationwide mechanics syllabus can be agreed upon at a future time, the panel makes the following two recommendations:

- The syllabus should include the study of rotational dynamics. It is important for students to learn to apply the laws of mechanics to extended bodies, not just point particles. Not only is the physics content important, but the study of rotational dynamics also presents substantial intellectual challenges that help prepare students for the challenges of their future higher education.
- There should be no distinction made between the study of mechanics with and without calculus. Whether or not the mathematical background of the students includes calculus, the concepts necessary for physics [e.g., ($\lim/\Delta t \rightarrow 0$) of ($\Delta x/\Delta t$)] can and should be introduced.

The primary goal of the study of Newtonian mechanics is to develop conceptual understanding, rather than the ability to perform complex mathematical manipulations. For example, it is not necessary for advanced high school students to learn how to calculate the moment of inertia of a cylinder about some given axis, but it is important for them to understand rotational kinetic energy and angular momentum.

The Role of Calculus in the New Common Mechanics Unit

The panel stresses that the new mechanics unit recommended above is by no means a noncalculus introduction to mechanics. Indeed, the concepts of calculus are absolutely essential to the physics subject matter. Specifically, the panel emphasizes the following points:

- Teachers with qualified students are encouraged to use formal calculus. Such students are eager to apply their mathematical prowess and should be encouraged to do so. It is likely that such students would continue their calculus-based study of physics in a second-semester course such as AP Physics C Electricity and Magnetism.[3]

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[3] AP Physics C Mechanics and AP Physics C Electricity and Magnetism are one-semester calculus-based courses, each leading to its own separate AP examination. AP Physics B is a two-semester noncalculus course leading to a single comprehensive AP Physics B examination. For a detailed discussion of the AP Physics program, see Chapter 3.

- The final examination for the new unit would not require students to use formal calculus. In all other respects, however, the new examination should be at about the same level as the current exam for AP Physics C Mechanics. This recommendation is in harmony with the current trend on that examination: less reliance on technical mathematics and increasing emphasis on conceptual physics (see Chapter 3).
- The final examination for the new unit would test students' knowledge of the concepts of both differential and integral calculus required to develop the physics. For example, students would be required to know that instantaneous velocity can be obtained as the slope of the graph of displacement versus time and that the work done by a force that varies as a function of position can be obtained from the area under the force curve.

Comparison of the New Mechanics Unit with Current AP Mechanics

Students who today would study AP Physics Mechanics C would find the new unit to be very much in line with their expectations for that course. There would be less emphasis on formal mathematics and more on conceptual understanding, but the general level of the treatment of the physics would be the same as that of current AP Physics C Mechanics. All the important physics currently found in AP Physics C Mechanics would still be covered and tested on the final examination.

Students who today would study AP Physics B would find the new mechanics unit to be a more comprehensive and in-depth treatment of the subject than that found in current Physics B courses, primarily because of the inclusion of rotational dynamics. Therefore, the primary effect for AP Physics students of the creation of a common mechanics unit as recommended by the panel would be to raise the standards in mechanics for Physics B to the level of Physics C.

Coverage of Other Areas of Physics

The breadth of material included in introductory college courses almost always requires rapid, superficial treatment. Unfortunately, the emphasis on breadth to the exclusion of depth is also growing at the secondary level, as more states are adopting encompassing frameworks and standards for science instruction. The panel believes, however, that for students to appreciate physics as a field of inquiry, it is more important for them to develop depth of understanding in the areas they study than to study any particular areas. The amount of additional material beyond Newtonian mechanics that can be covered in a particular course depends on its length. For a 1-year program, the panel believes strongly that students should study at most one other major area of physics.[4] In a 2-year program, the number of topics can be increased as long as the essential goal of depth of understanding is attained.

Additional Areas That Match Instructors' Talents and Resources

The panel believes that advanced physics programs should be able to choose from among various options the extra topics that best meet their needs. We offer the following possible optional topics for illustration only; a detailed list of options and a syllabus for each need to be carefully developed:

- Electricity and magnetism/circuits
- Models of light and sound (geometrical optics, mechanical waves, physical optics)
- Complex systems (thermal and statistical physics, computer-assisted conceptualization, chaos)
- Atomic, nuclear, and particle physics

Again, we are not proposing here the specific makeup of these other options; we are proposing that they be developed. In each case, physics teachers and students would be motivated to pursue greater depth of coverage in a limited area. We note that the ability to develop such options gives advanced high school instruction the flexibility needed to address emerging areas of physics, as discussed below.

Second Semester Options

In this section, we provide additional detail on some optional curricula that could be used in the second semester of an advanced physics program. In describing these options, we assume that students have already completed the new common mechanics unit discussed above. Our goal is not to specify these curricula completely; that is a task for other organizations, such as the College Board and the International Baccalaureate Organisation (IBO). Rather, the brief summaries below are intended to give the reader a better understanding of the overall content and goals of these example courses.

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[4] The panel is aware that many current AP Physics C programs spend the entire academic year on mechanics. We have no objection to this practice, which may well provide the extra time necessary for those students to achieve the depth of understanding that is the central objective of advanced physics study.

AP Physics C Electricity and Magnetism. This existing semester course is already familiar to many readers; it is the usual follow-up for students who take the current AP Physics C Mechanics course during the first semester. The content of the course is specified in the 2000/2001 edition of the *Advanced Placement Course Description: Physics*, published by the College Board (1999a) and known as the Acorn Book. (See Chapter 3 for a detailed discussion of the AP Physics program.)

The course is highly mathematical and covers Maxwell's equations in integral form. There are numerous applications of calculus, as well as an introduction to direct-current circuits. Capacitance and inductance are introduced, and the time dependence of currents and voltages in simple circuits is studied. The panel recommends decreased emphasis on the technical mathematical details and more emphasis on conceptual understanding. However, there is nothing to prevent this curriculum from being used as a second-semester option in its present form.

Biomedical Physics. The IBO has already defined a syllabus for the study of this topic in the *IB Diploma Programme Guide: Physics* (IBO, 2001). (See Chapter 3 for a detailed discuss of the IB physics program.) This noncalculus course covers the following major topics:

- Fluid statics, fluid flow, and the physics of the cardiovascular system
- Rotational statics, with application to the muscular-skeletal system
- Hearing—normal function, defects, and correction
- Radiation—types, sources, properties, and detection
- Medical imaging
- Biological effects, hazards, dosimetry, and diagnostic uses of radioactive sources

The course is currently designed to be covered in 30 hours, or approximately half a semester. Therefore, if the course were used as a semester option, several of these very interesting topics could be covered in greater depth, consistent with the fundamental goal of achieving deep conceptual understanding.

Special and General Relativity. This is another area for which the IBO has already created a detailed syllabus for a noncalculus course. The major topics covered by that syllabus include the following:

- Frames of reference and Galilean relativity
- Postulates and fundamental concepts of special relativity
- Historical context and experimental support for special relativity
- Postulates and fundamental concepts of general relativity
- Experimental support for general relativity (IBO, 2001)

Once again, the course is designed to be covered in 30 hours. However, this rich and intensely interesting subject lends itself to in-depth study in a myriad of ways. Indeed, a relativity option is likely to generate excitement and motivation for further study in physics—a key goal of advanced physics study cited earlier.

Fields at the Forefront of Current Physics Research as Optional Topics

One of the frustrating aspects of conventional physics instruction for new students is that they must spend years studying classical physics before they learn about fields at the forefront of current physics research. The teacher of an advanced high school program might well choose to use the time available after completing the required mechanics foundation to explore one of these fields.

Unlike conventional advanced physics study, which attempts to accelerate students in classical physics, the goal here would be advancement by enrichment. Such enrichment is an excellent way to generate enthusiasm for further study in physics, which, as noted above, is a key goal of any advanced high school physics program.

Examples of such enrichment might include a course on special and general relativity along the lines of Taylor and Wheeler's (2001) Spacetime Physics; a course that looks at quantum mechanics from a qualitative point of view; a course investigating nonlinear dynamics; a course in electricity and magnetism using a laboratory-based approach, such as the ZAP! Program by Morrison, Morrison, and Pine (1996); and a course in the history of particle physics, from the discovery of the electron to the confirmation of quarks. The intent of such courses would be to explore the topic with a depth and breadth commensurate with the mathematical sophistication of the students taking the course and the expertise of the teacher.

There are several potential advantages to this type of enrichment:

- The topics involved would often be exciting and speculative, appealing to students' taste for the exotic, and could motivate students to work and think at a more sophisticated level.
- Students would have more opportunities to exercise their critical and creative abilities than is the case in the highly defined and codified curriculum typical of the present AP and IB programs.
- Students could be better able to grasp the big picture of what is taking place in current physics research and to decide whether they want to be a part of that effort.
- Some course designs could provide real opportunities for long-term student-designed experiments and open-ended investigations.

- Students and teachers would have an incentive to use the Internet to identify research being done, to try out simulations, and to participate in distance learning opportunities or in organized forums addressing particular course topics in which researchers might cooperate as participants.
- Students and teachers might have an incentive to work with professionals from outside the school with expertise appropriate to the course, promoting both learning and broader collegial connections. College courses may already exist that could be adapted to create such courses.

There are also potential difficulties with such undertakings:

- The offerings might have to compete with more conventional advanced courses for a limited number of students.
- Colleges would be unlikely to grant credit or placement for these course offerings, since their content probably would not match that of college courses.
- Schools might not be willing to allocate the human and material resources needed to develop such courses.
- Teachers with sufficient expertise to teach the courses might not be available.

In addition to the above difficulties, no mechanism currently exists to validate that these course offerings provide the appropriate depth of understanding for advanced high school physics programs. Development of a mechanism for reviewing, certifying, and disseminating curricula and for training and certifying teachers in the use of such curricula would therefore be an essential part of advancement by enrichment. One possible approach would be for the American Physical Society and the American Association of Physics Teachers (AAPT) to establish a joint committee to operate as a Clearinghouse for Advanced Programs in Physics (CAP). Curriculum developers would submit proposed curricula to the CAP, which would then review them for quality of physics content, pedagogy, and interest to students. A curriculum passing the review would be certified as a CAP-Physics curriculum. Curriculum submitted during development might be issued a provisional certificate and reviewed again when in final form.

Once a curriculum had been granted a certificate, its developers could offer summer training institutes for teachers, subject to standards for such institutes issued by the CAP. Such standards might mandate a minimum time for the training and the makeup of the instructional staff. Teachers that completed the training satisfactorily, which might well involve passing a final examination on content, would be certified to offer the course in their schools. A school offering such a course, taught by a certified instructor, would be able to indicate the course on student transcripts as a CAP course.

Since CAP courses would not be designed to substitute for college courses, the CAP would not need to operate a testing program. It would, however, serve as an information source on available certified curricula and on summer institute programs for teacher certification. On the other hand, curriculum development groups might wish to have their own testing program, and test data could serve as additional evidence that a curriculum was suitable for CAP certification.

The key advantage of the CAP concept is that it would bring together many existing programs rather than having them continually reinvented by different groups. Most current curriculum projects that would be suitable for submission to the CAP already have teacher training provisions. The CAP would add nationally recognized certification of quality and disseminate certified curricula to schools across the nation.

Inclusion of Meaningful, Challenging, Real-World Experiences

Science at its heart is the process of how we come to know about and understand the physical world around us, including how living things interact with and are part of that world. What distinguishes science from other ways of thinking is reliance on evidence about the physical world and the importance of reproducible, principled consistency in judging the truth and utility of conjectures, laws, and theories. The panel strongly believes that all science courses at all levels—including advanced science courses in high schools—should include a significant component of experience with real-world phenomena and the way scientific conceptions are tested against observations of those phenomena. The panel acknowledges that in practice the interplay between theory and experiment is often complex. The important point is that science requires both components, and science instruction should reflect that interplay.

At the advanced high school physics level, students should already have had considerable experience with these activities in earlier physics and physical science courses[5] in the form of laboratory exercises, demonstrations, and perhaps even independent investigations. The panel believes that advanced physics courses should provide additional experiences for students in formulating their own conjectures and explanations, as well as in making the connections between real-world phenomena and the concepts, principles, and theories developed by the scientific community.

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[5] As noted earlier, there are special circumstances under which it may be appropriate for students to study advanced physics as a first-year physics course. In such cases, students may have no previous experience with laboratory physics, although it is highly likely that they will have laboratory experience in other sciences. It is the responsibility of the instructor to design the laboratory portion of the course to reflect prior student experience.

What form should these additional real-world experiences take? Evidence[6] indicates that traditional "cookbook" methods of laboratory instruction, in which students follow narrowly defined procedures to verify well-known principles, have little effect on students' conceptual understanding; on the other hand, substantial improvements in understanding are possible through rigorous, interactive laboratory experiences. Although much has been made of the need for "hands-on" activities in science, it is clear that what really matters is not "hands-on" but "minds-on." Cookbook labs are ineffective because students typically do very little thinking while they are working their way through the list of step-by-step instructions. Cookbook labs are mind-numbing experiences that lead students to describe their laboratory work as boring or a waste of time (NRC, 1997b). Indeed, in view of the fact that the time spent doing cookbook labs could be spent doing something more productive, it is doubtful that doing cookbook labs is better than doing no laboratory work at all.[7]

The research evidence against cookbook labs is not overwhelming, but we know of no research in their favor. The panel believes that the issue should be looked at from this point of view: What evidence is there that cookbook labs are of sufficient value to justify the enormous amount of time spent on them in physics programs across the nation? As far as we know, no evidence comes anywhere close to justifying this huge investment of effort.

Experimental work in advanced courses should provide experience with the way scientists use experiments—both for gathering data to build theoretical models and for exploring the applicability of these models to new situations. To that end, exploration of phenomena should generally precede and motivate the formal introduction of theoretical concepts. Moreover, students should make as many scientific decisions as possible, from the conception and design of the experiment all the way through the analysis, presentation, and critical review of the results.

The panel urges teachers of advanced physics courses to consider using a wide range of experiences, including the following (also see Box 2-1):

- Open-ended labs that require students to make decisions about what to observe, how to observe it, and how to interpret the data
- Labs that focus on allowing students to confront preconceptions and reconcile them with actual observations, with less emphasis on numerical data acquisition and analysis

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[6] An excellent discussion of effective laboratory instruction can be found in *Science Teaching Reconsidered* (NRC, 1997b, pp. 16–20).

[7] In the AP Physics Video Conference of November 10, 2000, cookbook labs were labeled as the lowest of five levels of lab work. The hope was expressed that AP physics students would rapidly progress to higher levels in which they would take increasing responsibility for the design and analysis of experiments.

BOX 2-1 Useful Resources for Developing Real-World Experiences

Although by no means exhaustive, the following is a list of some resources that members of the panel have found particularly helpful in developing meaningful real-world experiences. More information about many of these resources is given in Chapter 4:

- Edge, R.D. (1987). *String and sticky tape experiments*. College Park, MD: American Association of Physics Teachers.
- Sokoloff, D.R., Laws, P. W., and Thornton, R.K . (1994). *Real time physics: Active learning laboratories: mechanics.* Medford, MA: Tufts University.
- Sokoloff, D.R., Laws, P. W., and Thornton, R.K . (1997). *Real time physics: Active learning laboratories: Electric circuits.* Eugene, OR: Department of Physics, University of Oregon.
- Physics Teaching Resource Agents (PTRA) materials: available at the AAPT Web site.[8]
- Chabay, R.W., and Sherwood, B.A. (1999). *Electric and magnetic interactions.* New York: Wiley.
- CASTLE curriculum materials and experiments (capacitors, light bulbs, and batteries) (available through Pasco Scientific, Roseville, CA).
- Steinber, M., and Wainwright, C.L. (1993). Teaching electricity with models—The CASTLE Project. *Physics Teacher*, 31, 353.

- Demonstrations that encourage students to predict what is going to happen and then follow up with discussion that reconciles predictions and observations
- Take-home labs that can be done with relatively simple equipment and everyday items
- Exercises that work with data available on the Internet (e.g., data on sunspots gathered over many years as an indicator of periodic cycles in sunspot activity)

The panel would argue that a specific list of experiments is not useful; there are too many variations in the availability of time and equipment for such a list to be helpful. Both the College Board and the IBO provide lists of

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[8] Further information can be found by going to http://www.aapt.org [4/17/2002] and clicking on Programs and then PTRA.

labs that are commonly used in advanced secondary school physics courses, as well as in introductory college and university physics courses. Those lists can serve as a rough guide for teachers, although innovation is certainly to be encouraged. The panel also recommends that teachers of advanced courses be familiar with the AAPT's position papers on *The Role of Laboratory Activities in High School Physics* and *The Goals of the Introductory Physics Laboratory*, which describe aspects of the goals of experimental work in more detail.[9]

The way the experience is designed is more important than the specific topic. For example, a lab dealing with pendulum motion could be constructed as a rote exercise in data gathering to verify the dependence of the period of the pendulum's oscillatory motion on the length of the pendulum, but it would be better to design the experience as scientific inquiry. For example, the teacher might point out that some recent speculations about a so-called "fifth fundamental force" or extra space–time dimensions for gravity predict that the period of the pendulum motion should depend on the nature of the material of the pendulum bob—iron might behave differently from brass. The teacher might then ask what measurements should be carried out to test that idea and how well those measurements can be used to reject or confirm the idea. Still better would be a lab in which students would play with some pendulums first and then themselves come up with questions to ask about pendulum motion.

USE OF ASSESSMENTS THAT MEASURE DEPTH OF UNDERSTANDING

Assessments are a very important feature of any advanced physics program. Scoring well on a final examination is a tangible goal that both students and teachers can strive to achieve. Success on such examinations leads to feelings of triumph and looks good on college applications. In many cases, examination scores are also a major component of the school administration's evaluation of teacher performance.

Because of the high stakes involved, it is too often the assessments, rather than educational goals, that drive the instructional process. A prime example is the AP Physics B examination with its vast coverage of subject matter (see Chapter 3). In view of this fact, it is imperative that the assessments used accurately measure depth of understanding, the primary goal of advanced physics instruction. Unless the assessments encourage and reward students and teachers for exploring physics deeply in the ways described

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[9] These papers are available at the AAPT Web site—http://www.aapt.org [4/23/02]—under "AAPT Statements and Policies."

above, they will not do so; instead, they will do what is necessary to score well on the assessments. Ensuring that tests emphasize conceptual understanding is an important way to encourage better teaching practices.

In the next section, we offer some general recommendations for creating desirable written examinations. Written examinations are the most practical means of assessing the performance of a large number of candidates but are certainly not the only means. In particular, we draw the reader's attention to the internal assessment component of the IB physics program discussed in Chapter 3.

Designing Good Written Examinations

A good written examination in an advanced physics program should:

- **Emphasize conceptual questions, rather than mathematical techniques.** Here we are not distinguishing questions that are conceptual from those that are mathematical; conceptual questions may well involve mathematics. Rather, we are distinguishing questions that assess conceptual understanding from those that assess mainly technical mathematical skill.
- **Require explanation of the candidate's reasoning.** The goal of an advanced course is not just to provide the correct answer but also to communicate the reasoning process that leads to that answer.
- **Eliminate free-response questions that lead students through arguments by means of multiple interdependent parts.** Instead, shorter questions that call for original reasoning in a complex unfamiliar setting are desirable. Open-ended questions posed in a real-life setting can help strengthen the connection between physics and the world around us and are thus recommended.
- **Construct multiple-choice questions that reflect common student misconceptions.** Research is required to determine adequate distracters (incorrect multiple-choice answers). Ideally these distracters should be obtained from answers given previously by students to free-response questions. Additional improvements include multiple-choice questions that have more than one correct answer (multiple-completion questions) and multiple-choice questions that require not only the selection of a correct answer but also the selection of a correct justification.
- **Allow sufficient time for most well-prepared students to complete every question.** Emphasis must be placed on what a student knows—not how quickly the student can recall and use that knowledge.[10]

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[10] We are not suggesting that AP physics examinations be untimed. We simply want to provide sufficient time for well-prepared students to demonstrate their knowledge without being rushed.

- **Use innovative kinds of questions that probe depth of understanding.** Many alternative forms of assessment exercises exist, and some of these have been shown to be valuable. For example, students could be asked to score or rank a number of student solutions to a free-response question. Such an exercise would require not only understanding the question posed but also distinguishing among different models and recognizing the correct one.
- **Written examinations cannot accurately assess laboratory skills and should not attempt to do so.** However, questions involving analysis and interpretation of data are both reasonable and desirable. In addition, students can be asked to outline the design of simple experiments based on their general knowledge. Since there is no required list of experiments that all students must perform, such questions must not depend too strongly on the specifics of any particular experimental technique. Recent AP physics examinations contain many good examples of questions that satisfy these criteria.

Need for Improved Scoring Techniques

The scoring of written examinations must emphasize the evaluation of student understanding. A rigid scoring rubric in which points are awarded for highly specific correct responses to small parts of each question is not appropriate because it reduces the reader's ability to respond to student thinking (both correct and incorrect) not anticipated by the rubric. Rather, the reader should evaluate the student's response as a whole. A maximum score should be given only for complete and clear physical reasoning leading to the correct conclusions. Lower scores should be given for missing or erroneous reasoning, even if the conclusions reached are correct.

To understand this recommendation, it is important to distinguish between the allocation of maximum possible scores to different parts of the test and scoring rubrics of the type we decry. It is surely reasonable to allocate 10 points to problem 1, 15 points to problem 2, and so on. Similarly, it is reasonable to further subdivide the maximum possible credit for problem 1 among parts 1a, 1b, and 1c, as long as these parts are truly independent of each other. What is not reasonable, in our view, is to allocate 1 point for the statement of Newton's second law, 1 point for solving the resulting equations, 1 point for the numerical answer, and so on. Such rigidity makes it impossible to properly evaluate the student's reasoning, which is what we should be most interested in. Similar difficulties arise if parts 1a, 1b, and 1c are interdependent, since that will often allow students to answer the parts in many different orders and a wide variety of ways. If a question contains multiple interdependent parts (a practice against which the panel has argued above), it is better to evaluate the entire question as a whole.

To be clear, we are not advocating the abolition of all standardization of grading. Maintaining consistency in grading is indispensable to the fairness of the examination. Rather, we are advocating more flexible rubrics of the kind given on the College Board Web site in, say, U.S. History or English Literature. General guidelines are desirable; rigid rules for awarding each point are not. Moreover, we applaud the care shown by both the AP and IB programs in monitoring the consistency of the grading process and would expect such monitoring to continue.

Importance of High Standards for Success on Final Examinations

If the smaller and more manageable curriculum proposed earlier in this chapter were adopted, we would expect successful students to know the material in that curriculum thoroughly. Therefore, we recommend high standards of performance on the final examination for these students. While it is beyond the scope of the panel's work to propose specific standards, we believe the standards for awarding grades should be substantially higher than those currently in use by the two dominant programs. Currently, students can earn a grade of 5 in AP Physics B with raw scores that range anywhere from 106 to 180 points.[11] The panel is unanimous in asserting that this range is too broad; students who earn scores at the upper end of the range are better qualified than those at the lower end of the range. While this wide score range might serve a purpose in the current AP Physics program by allowing teachers to focus on some aspects of the curriculum at the expense of others without their students being penalized, a narrower score range would be more appropriate in the context of the more manageable curriculum proposed by the panel.

Less is known about the marking of IB assessments than about the scoring of AP examinations. However, the range of scores, particularly at the top, raises similar concerns about IB standards. The panel notes that IB students can obtain top marks on their examinations by earning 57 percent of the points for a 6 and 70 percent of the points for a 7.[12]

Additional evidence that standards for success on AP physics examinations should be higher can be found in an abstract by Howard Wainer of the Educational Testing Service that appeared recently (March 2001) on the College Board Web site. It states that students who were allowed to skip their first course in physics by virtue of success on the AP examination did not do

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[11] Data based on the *1998 Released Examinations* published by the College Board (1999b).

[12] The IB figures were estimated from information supplied by the IBO to the panel in the *subject report* for May 1999 (IBO, 1999b).

as well as students without AP experience in their second college physics course. This is particularly troubling in view of the fact that students with AP experience usually are among the most successful academically and normally outperform non-AP students. In fact, according to the abstract, AP students outperformed non-AP students in all but three disciplines: physics, economics, and U.S. government.

3

Extent to Which the AP and IB Programs Implement Recommended Practices

This chapter presents a critical review of the Advanced Placement (AP) and International Baccalaureate (IB) programs in light of the recommended practices set forth in Chapter 2. Before proceeding, it is important to make note of the differing backgrounds and goals of AP and IB physics.

Today, the AP and IB physics programs constitute the two most significant factors in defining what is meant by advanced study of physics in the United States. Most students entering the postsecondary education system each year who are identified as having completed an advanced physics course have participated in these two programs.

The reasons for the creation of the two programs were substantially different, and this led naturally to substantial differences in their approaches to advanced physics instruction. All judgments made in any comparison of the programs must be viewed through the lens of their distinctive histories and present structures.

THE AP PHYSICS PROGRAM

In this section, we respond directly to the questions under the panel's charge (see appendix) related to curriculum and assessment for the AP physics program. Where necessary, we distinguish between AP Physics B, a broad survey course without calculus, of the type often taken by students majoring in biology or health-related fields; and AP Physics C, a calculus-based introductory course in mechanics and electricity and magnetism, of the type generally taken by students concentrating in the physical sciences or engineering.

We note at the outset that both AP Physics B and AP Physics C are 1-year courses that are often taken by high school students as a first physics course,[13]

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[13] The College Board supplied the panel with the results of the background questions asked of the 1998 AP physics examination candidates. Approximately two-thirds of the 24,000

although that is not recommended by the College Board. As noted in Chapter 2, many students spend their entire academic year studying just the mechanics portion of AP Physics C. The additional time available makes it more reasonable to use advanced mechanics as a first course in physics.

Degree to Which the Factual Base of Information Provided by the AP Curriculum and Related Laboratory Experiences Is Adequate for Advanced High School Study in Physics

There is no question that the factual base of information provided by the AP physics curriculum and related laboratory experiences is fully adequate for a good advanced program. This factual base for AP physics is determined by the College Board through a poll of a large number of colleges to determine the content of their first-year physics courses (College Entrance Examination Board [CEEB], 2001).

The College Board does not mandate any specific laboratory experiences. Instead, it makes the general statement that in introductory college courses approximately 20 percent of the credit awarded can be attributed to laboratory performance (CEEB, 2001, p. 10). In addition, the effectiveness of laboratory experiences is greatly dependent on the particular implementation of laboratory instruction in each individual high school (see Chapter 2). Therefore, it is impossible to determine the adequacy of laboratory experiences definitively for the entire AP physics program.

Extent to Which the AP Curriculum and Assessments Balance Breadth of Coverage with In-Depth Study of Important Topics in Physics

AP Physics C is a reasonable-sized 1-year physics course with respect to the content covered. It is, in fact, one implementation of the model presented in Chapter 2—Newtonian mechanics with an electricity and magne-

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Physics B candidates had taken only two or fewer semesters of physics in high school prior to attempting the examination. The situation is reversed for Physics C, with about three-fifths of the candidates having taken three or more semesters of physics prior to the examination. The number of 1998 Physics B candidates was approximately twice the number of Physics C candidates, so that well over half of all 1998 AP physics candidates had taken two or fewer semesters of physics prior to attempting their examinations. About half of the Physics C candidates (6,000 students) took only the mechanics and not the electricity/magnetism exam. About half of this mechanics-only group had taken two semesters or fewer of physics in high school. This suggests that a substantial number of students are using AP Physics C Mechanics as a first-year physics course.

tism option. Indeed, students are examined separately on mechanics and electricity and magnetism and can choose to take either or both examinations. AP Physics C is appropriately balanced between breadth and depth. However, it makes mathematical demands that are not appropriate for all students.

By contrast, AP Physics B is a gigantic course that is nearly impossible to cover properly in a single year. It encourages cursory treatment of very important topics in physics in a way the panel believes is inappropriate for an advanced high school course. Such a large amount of material should clearly be spread over 2 years. If the recommendations presented in Chapter 2 were implemented, AP Physics B would cease to exist as a 1-year program.

We emphasize that an advanced physics curriculum should focus more on conceptual understanding and less on mathematical manipulation. For example, it is much more important that students understand intuitively the consequences of shorting out a circuit element than that they be able to solve numerous simultaneous linear equations obtained from Kirchhoff's laws. To better illustrate the difference between these two kinds of knowledge, Box 3-1 presents a case study done by Professor Eric Mazur of Harvard University, a member of this panel (Mazur, 1997).

Degree to Which AP Physics Courses Are Organized Around Key Concepts to Promote Conceptual Understanding

As discussed in Chapter 2, Newtonian mechanics should provide the conceptual foundation for all advanced physics programs. Both AP courses have a substantial mechanics component, but AP Physics C Mechanics, with its coverage of rotational dynamics, is closer to the Newtonian mechanics foundation recommended for all advanced high school physics programs in Chapter 2. On the other hand, we believe that the current AP Physics C Mechanics curriculum contains excessive mathematical complexity that should be eliminated in favor of increased emphasis on conceptual understanding.

Degree to Which the AP Physics Curriculum and Related Laboratory Experiences Provide Opportunities for Students to Apply Their Knowledge to a Range of Problems in a Variety of Contexts

The AP curriculum provides ample material for problem solving. Indeed, problem solving is an indispensable part of any advanced physics course. However, the range and variety of contexts of problems can vary

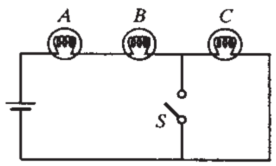
BOX 3-1 Excerpt from *Peer Instruction: A User's Manual*

Introduction

MEMORIZATION VERSUS UNDERSTANDING

To understand these seemingly contradictory observations, I decided to pair, on subsequent examinations, simple qualitative questions with more difficult quantitative problems on the same physical concept. An example of a set of such questions on dc circuits is shown in Figure 1.1. These questions were given as the first and last problem on a midterm examination in the spring of 1991 in a conventionally taught class (the other three problems on the examination, which were placed between these two, dealt with different subjects and are omitted here).

1. A series circuit consists of three identical light bulbs connected to a battery as shown here. When the switch *S* is closed, do the following increase, decrease, or stay the same?



(*a*) The intensities of bulbs *A* and *B*
(*b*) The intensity of bulb *C*
(*c*) The current drawn from the battery
(*d*) The voltage drop across each bulb
(*e*) The power dissipated in the circuit

5. For the circuit shown, calculate (*a*) the current in the 2-Ω resistor and (*b*) the potential difference between points *P* and *Q*.

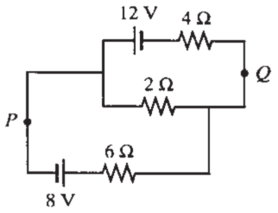


Figure 1.1 Conceptual (top) and conventional question (bottom) on the subject of dc circuits. These questions were given on a written examination in 1991.

Notice that question 1 is purely conceptual and requires only a knowledge of the fundamentals of simple circuits. Question 5 probes the students' ability to deal with the same concepts, now presented in the conventional numerical format. It requires setting up and solving two equations using Kirchhoff's laws. Most physicists would consider question 1 easy and question 5 harder. As the result in Figure 1.2 indicates, however, students in a conventionally taught class would disagree.

Analysis of the responses reveals the reason for the large peak at 2 for the conceptual question: Over 40% of the students believed that closing the switch doesn't change the current through the battery but that the current splits into two at the top junction and rejoins at the bottom! In spite of this serious misconception, many still managed to correctly solve the mathematical problem.

Figure 1.3 shows the lack of correlation between scores on the conceptual and conventional problems of Figure 1.1. Although 52% of the scores lie on the broad diagonal band, indicating that these students achieved roughly equal scores on both questions (±3 points), 39% of the students did substantially worse on the conceptual question. (Note that a number of students managed to score zero on the conceptual question and 10 on the conventional one!) Conversely, far fewer students (9%) did worse on the conventional question. This trend was confirmed on many similar pairs of problems during the remainder of the semester: Students tend to perform significantly better when solving standard textbook problems than when solving conceptual problems covering the same subject.

This simple example exposes a number of difficulties in science education. First, it is possible for students to do well on conventional problems by memorizing algorithms without understanding the underlying physics. Second, as a result of this, it is possible for a teacher, even an experienced one, to be completely misled into thinking that students have been taught effectively. Students are subject to the same misconception: They believe they have mastered the material and then are severely frustrated when they discover that their plug-and-chug recipe doesn't work in a different problem.

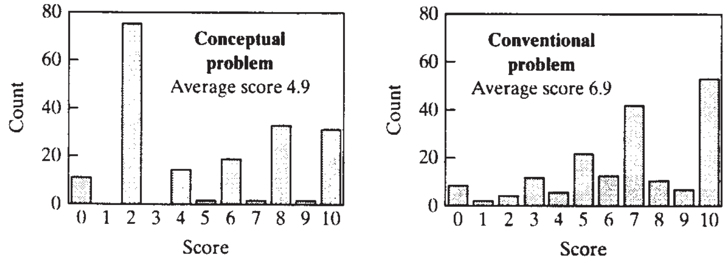


Figure 1.2 Test scores for the problems shown in Figure 1.1. For the conceptual problem, each part was worth a maximum of 2 points.

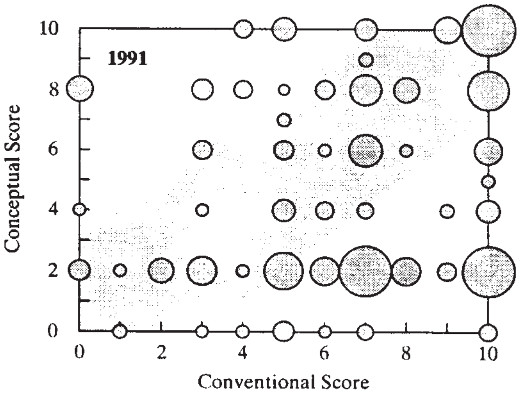


Figure 1.3 Correlation between conceptual and conventional problem scores from Figure 1.2. The radius of each datapoint is a measure of the number of students represented by that point.

Clearly, many students in my class were concentrating on learning "recipes," or "problem-solving strategies" as they are called in textbooks, without considering the underlying concepts. Plug and chug! Many pieces of the puzzle suddenly fell into place:

- The continuing requests by students that I do more and more problems and less and less lecturing—isn't this what one would expect if students are tested and graded on their problem-solving skills?
- The inexplicable blunders I had seen from apparently bright students—problem-solving strategies work on some but surely not on all problems.
- Students' frustration with physics—how boring physics must be when it is reduced to a set of mechanical recipes that do not even work all the time!

SOURCE: Mazur (1997).

substantially among specific implementations at different high schools. Therefore, the opportunities advanced students have to apply their knowledge to problems in a variety of contexts depend upon the particular AP physics program in which they are enrolled.

Extent to Which the AP Physics Curriculum and Related Laboratory Experiences Encourage Students and Teachers to Make Connections Among the Various Disciplines in Science and Mathematics

The connection between physics and mathematics is very strong, and both AP physics courses call upon students to use their mathematical skills to the fullest. Indeed, it is not unusual for students to say after they have taken AP physics that they appreciate the great value of mathematics for the first time.

On the other hand, the AP physics program does not encourage students and teachers to connect physics with other areas of science. Rather, such connections are made at the discretion of individual teachers or high schools. These decisions may be shaped by such factors as opportunities for departments to interact or plan courses together or by the textbooks selected for the course.

Laboratory experiences can indeed be used to make interdisciplinary connections. Yet because the nature of laboratory experiences varies substantially among the implementations of AP physics at different high schools, it is impossible to answer this question for the AP physics program as a whole. For a thorough discussion of the importance of laboratory experiences in advanced physics study, see Chapter 2.

Extent to Which Final Assessments in AP Physics Measure or Emphasize Students' Mastery of Content Knowledge

The coverage of topics on the Physics B examination is excessively broad. The coverage of topics on the Physics C examination is appropriate, although the nature of the questions (discussed below) may encourage instructional approaches that emphasize mathematical technique rather than conceptual understanding. In that case, students may experience the course as a nonhierarchical litany of facts and formulas (Eylon and Reif, 1984)—effectively too broad and shallow.

On both AP Physics B and C examinations, the standards for success are low. Indeed a 5, the highest possible score, can be obtained for a score of about 60 percent of the total points available, and a 4 is sometimes given for scores under 40 percent. The College Board justifies this as a way of allowing students to skip examination questions on topics they may not have covered in class. This justification appears plausible for AP Physics B, with its very broad curriculum; however, it is difficult to see how this reasoning can be applied to AP Physics C, with its much narrower curriculum. Allowing students to skip unfamiliar questions on the examinations can be viewed as a means of permitting instructors who are so inclined to pursue fewer topics in greater depth. The panel members' experiences in preparing students for high-stakes examinations lead us to suspect, however, that few instructors adopt this strategy (this is a question for study) and that the breadth of the examinations is strong motivation for breadth of coverage in instruction.

If the curriculum changes recommended in Chapter 2 were adopted, student mastery of content knowledge could be accurately assessed with improved examinations. At present, the need for the examination to reflect the broad content of the curriculum accurately and consistently, coupled with the low standards discussed above, means that mastery is not being assessed. It is the nature of high-stakes testing that if the test does not assess mastery, teachers will not teach mastery, and most students will therefore not gain it.

Extent to Which Final Assessments in AP Physics Measure or Emphasize Students' Understanding and Application of Concepts

Many of the questions on previous AP physics examinations value technique over conceptual understanding. However, the trend on recent AP physics examinations has definitely been in the direction of increasing the emphasis on conceptual understanding—as it should be. Examples of problems taken from previous AP examinations are presented below. We also note that because the entire final assessment in AP physics is by means of a single written examination, it is not possible to assess the laboratory skills of AP physics students (see Chapter 2).

In general, AP physics examinations require students to do too much in too short a time. Either the time should be lengthened or the amount of material reduced so that students can complete the entire examination. The time issue is important not only because it affects the reliability of the assessment but also because it influences the instructional practices used in preparing students to take the examination. Preparing students to answer many questions in a short amount of time may not be conducive to instilling in them good scientific habits of mind (see Chapter 2).

The following subsections present four sample problems taken from actual AP physics examinations (CEEB, 1994a, 1994b, 1999b). The examples taken from the 1993 exams are the kind of technical problems of which we have been critical, while those taken from the 1998 exams are good problems that emphasize conceptual understanding.

A key issue in these examples is the role of mathematics in good free-response questions. We stress that there are two very different aspects of the use of mathematics in physics problems. First is the translation of parts of physical reality into mathematical models that are usually expressed in the form of equations. Skill in this kind of translation is an important indicator of deep conceptual understanding of physical principles, and its assessment with examination questions is entirely appropriate. Second is the manipulation of the mathematical models to arrive at final results. Skill in this use of mathematics certainly has value but has little to do with the conceptual understanding of physics. Good mathematical examination questions should therefore emphasize skill in the translation of physical reality into mathematics and downplay the subsequent mathematical manipulations. The panel's remarks about the examples given in the following subsections should be viewed in light of this principle.

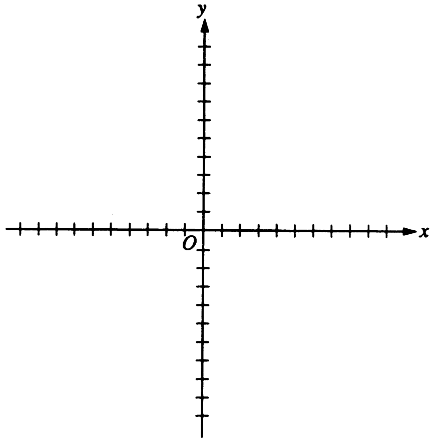
The reader may ask why we do not also present sample multiple-choice questions. It could be argued that, especially since calculators are not permitted on the multiple-choice portion of the AP examinations, many multiple-choice questions are conceptual in nature. However, the panel believes a reliable assessment of the understanding of students can be made only by requiring students to explain their reasoning and then carefully evaluating those explanations, as discussed in Chapter 2. Since the panel regards the assessment of understanding as the primary goal of examinations, the examples given below are taken from the free-response portion of the examinations.

1993 AP Physics B, Problem 2. This problem (see Figure 3-1) calls for the direct use of the formulas for the electric field and potential of point charges, with a small amount of vector addition required in one part. It is more of a mathematics problem than a physics problem. Although important physical principles play some role (superposition of electric fields and the connection between work and potential energy), the problem could be answered correctly by a student who had memorized the relevant formulas and techniques. The problem is thus a poor tool for assessing conceptual understanding.

1998 AP Physics B, Problem 6. This problem (see Figure 3-2) is similar to the questions asked in the Force Concept Inventory (Hestenes, Wells, and Swackhamer, 1992). There is nothing to calculate, yet the problem tests extremely important concepts in projectile motion and Newton's laws.

2. A charge $Q_1 = -16 \times 10^{-6}$ coulomb is fixed on the x-axis at $+4.0$ meters, and a charge $Q_2 = +9 \times 10^{-6}$ coulomb is fixed on the y-axis at $+3.0$ meters, as shown on the diagram above.

(a) i. Calculate the magnitude of the electric field E_1 at the origin O due to charge Q_1.
ii. Calculate the magnitude of the electric field E_2 at the origin O due to charge Q_2.
iii. On the axes below, draw and label vectors to show the electric fields $\mathbf{E}_1$ and $\mathbf{E}_2$ due to each charge, and also indicate the resultant electric field $\mathbf{E}$ at the origin.



(b) Calculate the electric potential V at the origin.

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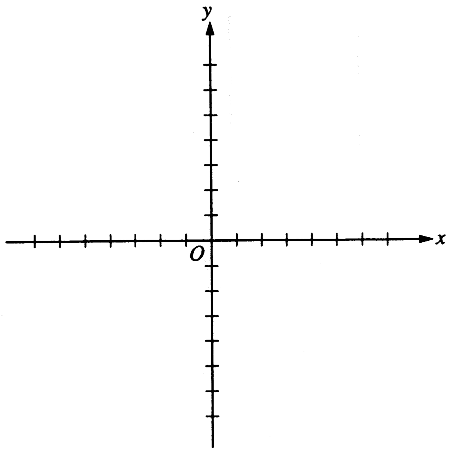
FIGURE 3-1 1993 AP Physics B problem 2

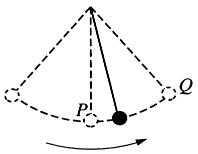
A charge $Q_3 = -4 \times 10^{-6}$ coulomb is brought from a very distant point by an external force and placed at the origin.

(c) On the axes below, indicate the direction of the force on Q_3 at the origin.



(d) Calculate the work that had to be done by the external force to bring Q_3 to the origin from the distant point.

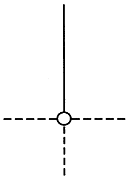
FIGURE 3-1 1993 AP Physics B problem 2 (continued)
SOURCE: (CEEB, 1994a).



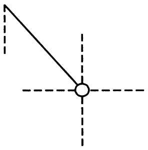
6. (10 points)
A heavy ball swings at the end of a string as shown above, with negligible air resistance. Point P is the lowest point reached by the ball in its motion, and point Q is one of the two highest points.

(a) On the following diagrams draw and label vectors that could represent the velocity and acceleration of the ball at points P and Q. If a vector is zero, explicitly state this fact. The dashed lines indicate horizontal and vertical directions.

i. Point P

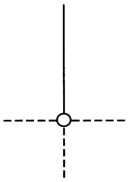


ii. Point Q



(b) After several swings, the string breaks. The mass of the string and air resistance are negligible. On the following diagrams, sketch the path of the ball if the break occurs when the ball is at point P or point Q. In each case, briefly describe the motion of the ball after the break.

i. Point P



ii. Point Q

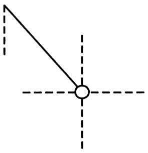


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FIGURE 3-2 1998 AP Physics B problem 6
SOURCE: (CEEB, 1999b)

1993 AP Physics C Mechanics, Problem 2. This problem (see Figure 3-3) is almost entirely a mathematics problem, involving the solution of an elementary differential equation that many AP Physics students would know from memory. The first two parts contain a rudimentary application of Newton's second law.

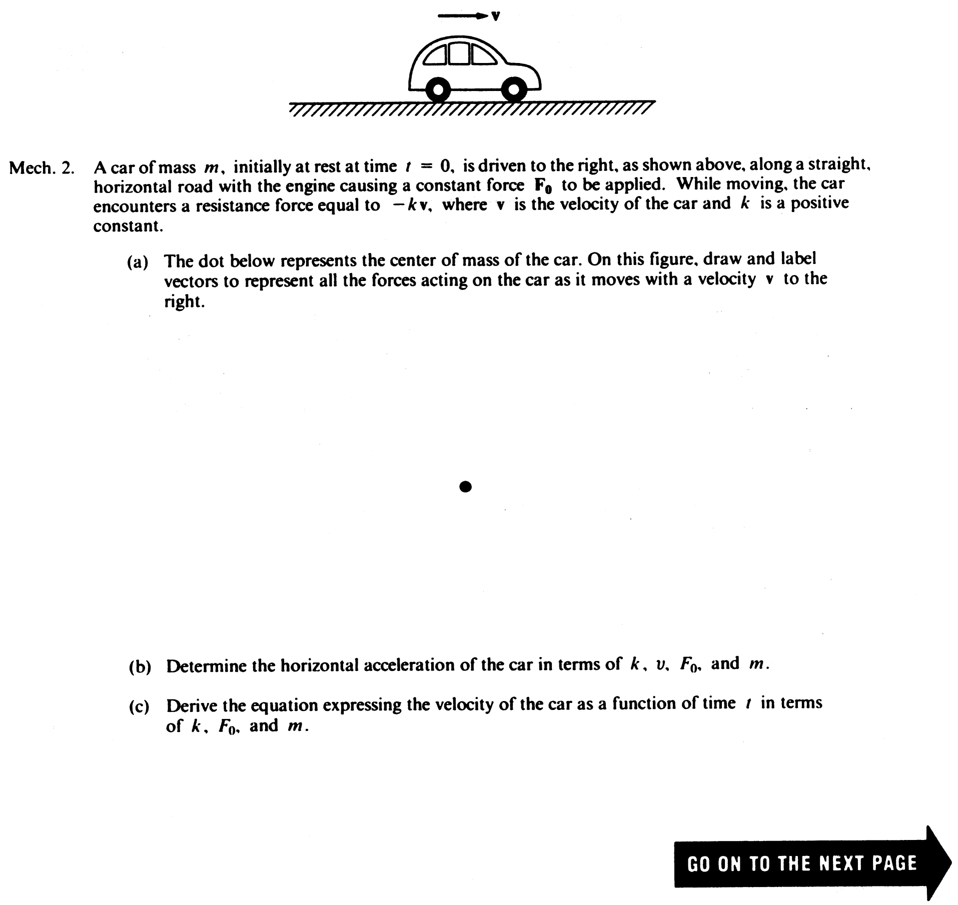
1998 AP Physics C Electricity and Magnetism, Problem 3. This question (see Figure 3-4) is full of important physics. Newton's laws must be used to express the balance between the component of the weight along the incline and the magnetic force. Faraday's law, Lenz's law, and Ohm's law are all necessary in different parts of the question. Although there is a considerable amount of mathematics involved in part (d), part (e) is a good qualitative question that can be answered from different points of view. We stress that mathematics may be well be necessary to answer some good examination questions, but it is essential that the question focus on important physical concepts.

Extent to Which Final Assessments in AP Physics Measure or Emphasize Students' Ability to Apply What They Have Learned to Other Courses and in Other Situations

The AP physics examinations do very little to measure or emphasize students' ability to apply what they have learned to other fields and situations. The exams are strictly limited to narrowly defined physics content. However, the questions posed sometimes ask students to apply the physical principles they know to situations they may not have previously encountered.

Summary of the Panel's Evaluation of the AP Physics Program

- The AP Physics B program is too broad and should be eliminated as a 1-year course.
- The mechanics components of AP Physics B and C should be merged into a single common mechanics component (see Chapter 2).
- AP Physics students in a 1-year program should complete the mechanics program and study at most one other major area of physics. They should be examined separately in each area; standards for success should be high.
- Examinations should emphasize conceptual understanding rather than mathematical manipulation. Recommendations for improving examinations are given in Chapter 2.



Mech. 2. A car of mass m, initially at rest at time $t = 0$, is driven to the right, as shown above, along a straight, horizontal road with the engine causing a constant force $\mathbf{F_0}$ to be applied. While moving, the car encounters a resistance force equal to $-k\mathbf{v}$, where $\mathbf{v}$ is the velocity of the car and k is a positive constant.

(a) The dot below represents the center of mass of the car. On this figure, draw and label vectors to represent all the forces acting on the car as it moves with a velocity $\mathbf{v}$ to the right.

(b) Determine the horizontal acceleration of the car in terms of k, v, F_0, and m.

(c) Derive the equation expressing the velocity of the car as a function of time t in terms of k, F_0, and m.

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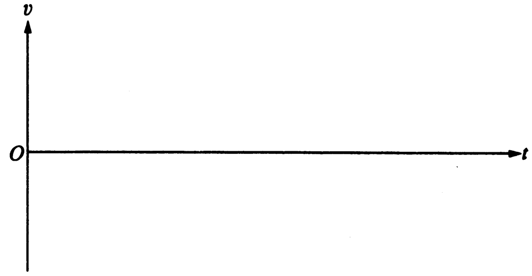
FIGURE 3-3 1993 AP Physics C Mechanics, problem 2

(d) On the axes below, sketch a graph of the car's velocity v as a function of time t. Label important values on the vertical axis.



(e) On the axes below, sketch a graph of the car's acceleration a as a function of time t. Label important values on the vertical axis.

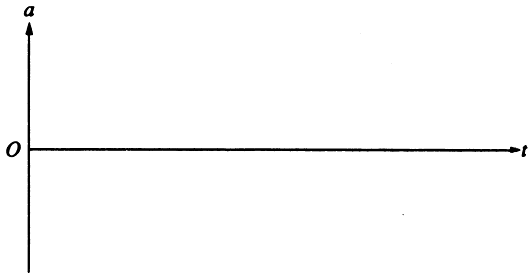


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FIGURE 3-3 1993 AP Physics C Mechanics, problem 2 (continued)
SOURCE: (CEEB, 1994b)

- Accomplishing the necessary improvements will require a willingness to alter radically the philosophy of AP Physics examinations. During the transition, the meaning of examination scores will change, so that they may not be consistent with scores on earlier exams. It will therefore be necessary to give up consistency in the statistics of examination scores from year to year as the transition occurs.

THE IB PHYSICS PROGRAM

In this section, we respond directly to the questions under the panel's charge (see appendix) related to curriculum and assessment for the IB physics program. By IB physics we mean the Higher Level (HL) IB Physics course, a 2-year course. In contrast to AP physics, the curriculum for IB physics is spelled out quite thoroughly by the International Baccalaureate Organisation (IBO), down to the number of hours to be spent teaching each rather small division of subject matter.[14] For example, 1 hour of teaching time is allocated to the introduction of vectors and scalars, the addition of coplanar vectors by graphical means, and multiplication of vectors by scalars (IBO, 1996, p. 22). In all phases of the course, students are required to spend approximately 25 percent of their time following an internally assessed scheme of practical/investigative work (106).

Schools pay an annual fee to the IBO in order to offer IB courses, and the IBO vigorously enforces its detailed standards for each of its courses offered by a school through periodic inspections and evaluations. IB credit is available only to students who have both completed the IB course and received an acceptable score on the final IB assessment. Again, this practice contrasts sharply with the AP program, in which any student who pays the examination fee can take an AP examination in any subject.

Degree to Which the Factual Base of Information Provided by the IB Curriculum and Related Laboratory Experiences Is Adequate for Advanced High School Study in Physics

There is no question that the factual base of information provided by the IB physics curriculum and related laboratory experiences is fully adequate for a good advanced program. The factual base for IB physics is

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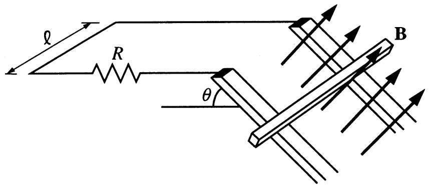
[14] The careful specification of the IB physics curriculum, however, should not be construed as requiring either a particular order of instruction or definite teaching times. The new IB Physics Guide for first examinations in 2003 makes clear that this detailed information is intended only as a guide (IBO, 2001, p. 4).



E & M. 3. A conducting bar of mass m is placed on two long conducting rails a distance ℓ apart. The rails are inclined at an angle θ with respect to the horizontal, as shown above, and the bar is able to slide on the rails with negligible friction. The bar and rails are in a uniform and constant magnetic field of magnitude B oriented perpendicular to the incline. A resistor of resistance R connects the upper ends of the rails and completes the circuit as shown. The bar is released from rest at the top of the incline. Express your answers to parts (a) through (d) in terms of m, ℓ, θ, B, R, and g.

(a) Determine the current in the circuit when the bar has reached a constant final speed.

(b) Determine the constant final speed of the bar.

(c) Determine the rate at which energy is being dissipated in the circuit when the bar has reached its constant final speed.

(d) Express the speed of the bar as a function of time t from the time it is released at $t = 0$.

(e) Suppose that the experiment is performed again, this time with a second identical resistor connecting the rails at the bottom of the incline. Will this affect the final speed attained by the bar, and if so, how? Justify your answer.

FIGURE 3-4 1998 AP Physics C Electricity/Magnetism, problem 3
SOURCE: (CEEB, 1999b)

approximately the same as that for AP Physics B, except that the time allotted is a much more reasonable 2 years.

As in the case of AP physics, the IB program does not mandate the completion of specific laboratory exercises. However, IB physics students must spend 25 percent of their time doing practical/investigative work "over a prolonged period"[15] (IBO, 1996, p. 106). This time need not be devoted entirely to conventional laboratory exercises; computer simulation studies would also be acceptable, for example. However, because teachers of advanced physics courses need to be able to adjust their teaching objectives and techniques in response to their continuing evaluation of the understanding of their students (see Chapter 4), the panel believes the 25 percent requirement is too inflexible.

Extent to Which the IB Curriculum and Assessments Balance Breadth of Coverage with In-Depth Study of Important Topics in Physics

Because the IB physics program spans a 2-year period, it does not suffer from the same problems as AP Physics B. The material can reasonably be covered in considerable depth in a 2-year course.

IB physics contains no calculus and as a result cannot pursue the detailed study of electric and magnetic fields found in AP Physics C. The panel believes that the mathematical study of electricity and magnetism should be an available option in the IB program that could be selected by an instructor with mathematically advanced students.[16]

Degree to Which IB Physics Courses Are Organized Around Key Concepts to Promote Conceptual Understanding

As noted above, the panel believes Newtonian mechanics should provide the conceptual foundation for all advanced physics programs. IB physics contains a strong Newtonian mechanics component. In addition, there are already a number of well-defined optional topics that can be selected by individual IB instructors, as recommended in Chapter 2.

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[15] This practical work is internally assessed and must last for at least two-thirds of the time the course is taught.

[16] At one time, the IB program contained an Electricity and Magnetism option that required calculus. The option was dropped because it was not popular. This does not prevent IB teachers from using calculus with mathematically advanced students; however, current IB examinations do not contain questions that require the use of calculus.

The mechanics component of IB physics currently includes rotational dynamics, as recommended in Chapter 2. However, the new IB physics syllabus (IBO, 2001), which applies to any student starting the 2-year program in August 2001 or later, does not include this topic.

Degree to Which the IB Physics Curriculum and Related Laboratory Experiences Provide Opportunities for Students to Apply Their Knowledge to a Range of Problems in a Variety of Contexts

The IB curriculum provides ample material for problem solving. Indeed, as noted earlier, problem solving is an indispensable part of any advanced physics course. As with the AP program, however, the range and variety of contexts of problems can vary substantially among specific implementations at different high schools. Therefore, the opportunities advanced students have to apply their knowledge to problems in a variety of contexts depends upon the particular IB physics program in which they are enrolled.

Extent to Which the IB Physics Curriculum and Related Laboratory Experiences Encourage Students and Teachers to Make Connections Among the Various Disciplines in Science and Mathematics

As noted earlier, the connection between physics and mathematics is very strong, and the IB physics course calls upon students to use substantial mathematical skills. However, the IB physics course does not use calculus.

Some of the IB options, such as Biomedical Physics and Historical Physics, connect physics with other disciplines. In addition, all students are required to carry out a Group 4 project in which students are encouraged to combine concepts from different disciplines in a collaborative, investigative experience (IBO, 2001, pp. 27–32). There is great flexibility in the choice of projects and the types of work required; it is therefore difficult to evaluate the educational impact of the Group 4 project requirement.

Extent to Which Final Assessments in IB Physics Measure or Emphasize Students' Mastery of Content Knowledge

The IB HL Physics final assessment is much more extensive than its AP counterpart. There are three written papers that together account for 76 percent of the student's final IB score (given on a 1–7 scale): a 1-hour section consisting of 40 multiple-choice questions; a $2^1/_4$-hour free-response section containing one data-based question, several short-answer questions, and one extended-response question; and a $1^1/_4$-hour free-response section on the two optional topics studied (IBO, 2001, p. 14). Students have minimal freedom in selecting which questions to answer on the second paper. In contrast, students are required to answer all questions on the AP examinations.

The pace of the IB examinations is much more leisurely than that of the AP examinations, which require a student to complete 70 multiple-choice questions in 90 minutes and then six to eight free-response problems in a further 90 minutes. Of course, a precise comparison of the time pressure involved in different examinations requires a careful comparison of the questions asked on each exam. Nevertheless, the panel reviewed a considerable number of examinations in each program and is confident in its assessment that IB examinations create far less time pressure than AP examinations.

The IB examination also allows a 10-minute reading time for written papers. During this time, students can review the paper to decide what questions to answer but cannot do any written work. The exam time starts after the reading time. The panel applauds the longer time allowed in the IB case; as discussed in Chapter 2, we firmly believe in giving students the time they need to think.

The questions on the IB physics examinations are generally of a more conceptual nature than those on the AP physics examinations (as discussed below), another feature the panel applauds. Nevertheless, the written IB physics examinations suffer from many of the same problems discussed in Chapter 2:

- Too many questions have multiple parts that lead students through the solution.
- Insufficient attention is paid to reasoning in the scoring rubrics. Too rarely is credit deducted for incorrect statements.
- Rigid scoring rubrics need to be replaced by an overall evaluation of the totality of each student's response.
- The standards for success on IB examinations are comparable to those on AP examinations—far too low, in the opinion of the panel.

The remaining 24 percent of each student's IB score comes from an internal assessment made by the IB teacher of the student's laboratory work. To make this assessment, the teacher applies a set of stringent criteria that are carefully spelled out by the IBO (2001, pp 15–26). The IBO requires sample papers from schools to verify that these criteria are being applied correctly. Thus the IB final examination provides for an assessment of laboratory skills—something entirely lacking in the AP program. However, the larger question remains of whether the laboratory investigations of IB students are really meaningful educational experiences. If they are not, they are not worth assessing.

Extent to Which Assessments in IB Physics Measure or Emphasize Students' Understanding and Application of Concepts

As mentioned in the preceding section, IB physics examinations generally place more emphasis on conceptual understanding than their AP counterparts, as illustrated by the two examples given below. However, this emphasis is still insufficient to enable a reliable assessment of such understanding for the reasons discussed earlier.

Figure 3-5 is question #A2 from paper 2 of the November 1999 IB Physics HL examination. There is nothing to calculate, yet the question tests students' understanding of Newton's second law in a variety of settings. It is an excellent conceptual question.

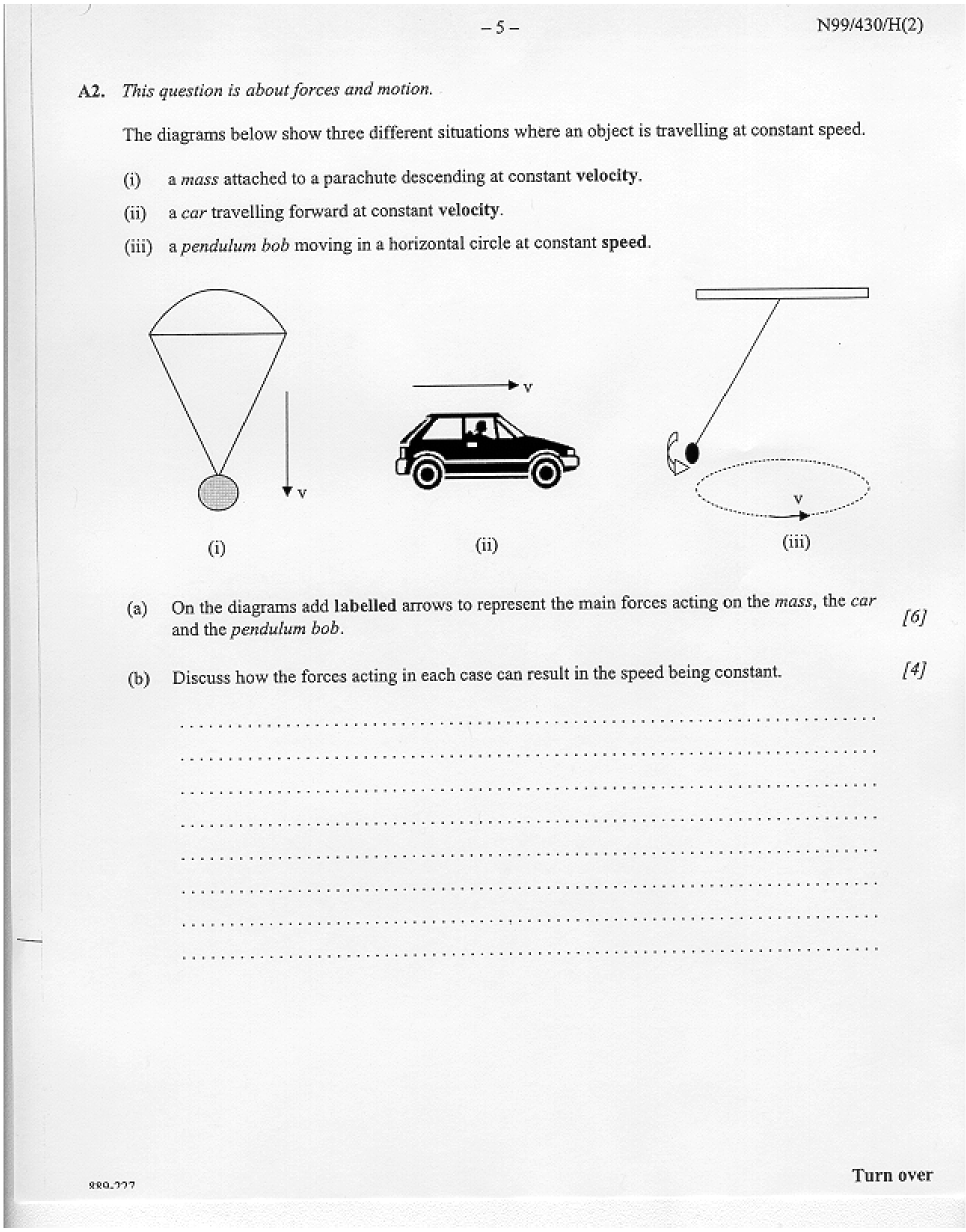
Figure 3-6 is question #B3 from the same examination paper. Part (a) of the problem begins with two "plug-in" uses of the formulas for projectile motion, but then continues with a graph in which students need to demonstrate their understanding of the oscillatory nature of the motion of the ball. The problem then continues with two short essay parts in which students have to explain physical principles. Part (b) is largely an exercise in the use of simple formulas, but part (c) contains another short essay question that tests students' understanding of angular momentum conservation.

Extent to Which Final Assessments in IB Physics Measure or Emphasize Students' Ability to Apply What They Have Learned to Other Courses and in Other Situations

The final assessments in IB physics do little to measure or emphasize students' ability to apply what they have learned to other fields and situations. Yet they perhaps do somewhat more than the AP examinations in this regard because of the inclusion of optional units that are interdisciplinary in nature.

Summary of the Panel's Evaluation of the IB Physics Program

- The IB physics program is a good 2-year course. With respect to the pace at which it addresses topics, covering largely the same material as AP Physics B, it may be ideal.



– 5 – N99/430/H(2)

A2. *This question is about forces and motion.*

The diagrams below show three different situations where an object is travelling at constant speed.

(i) a *mass* attached to a parachute descending at constant **velocity**.
(ii) a *car* travelling forward at constant **velocity**.
(iii) a *pendulum bob* moving in a horizontal circle at constant **speed**.

(a) On the diagrams add **labelled** arrows to represent the main forces acting on the *mass*, the *car* and the *pendulum bob*. *[6]*

(b) Discuss how the forces acting in each case can result in the speed being constant. *[4]*

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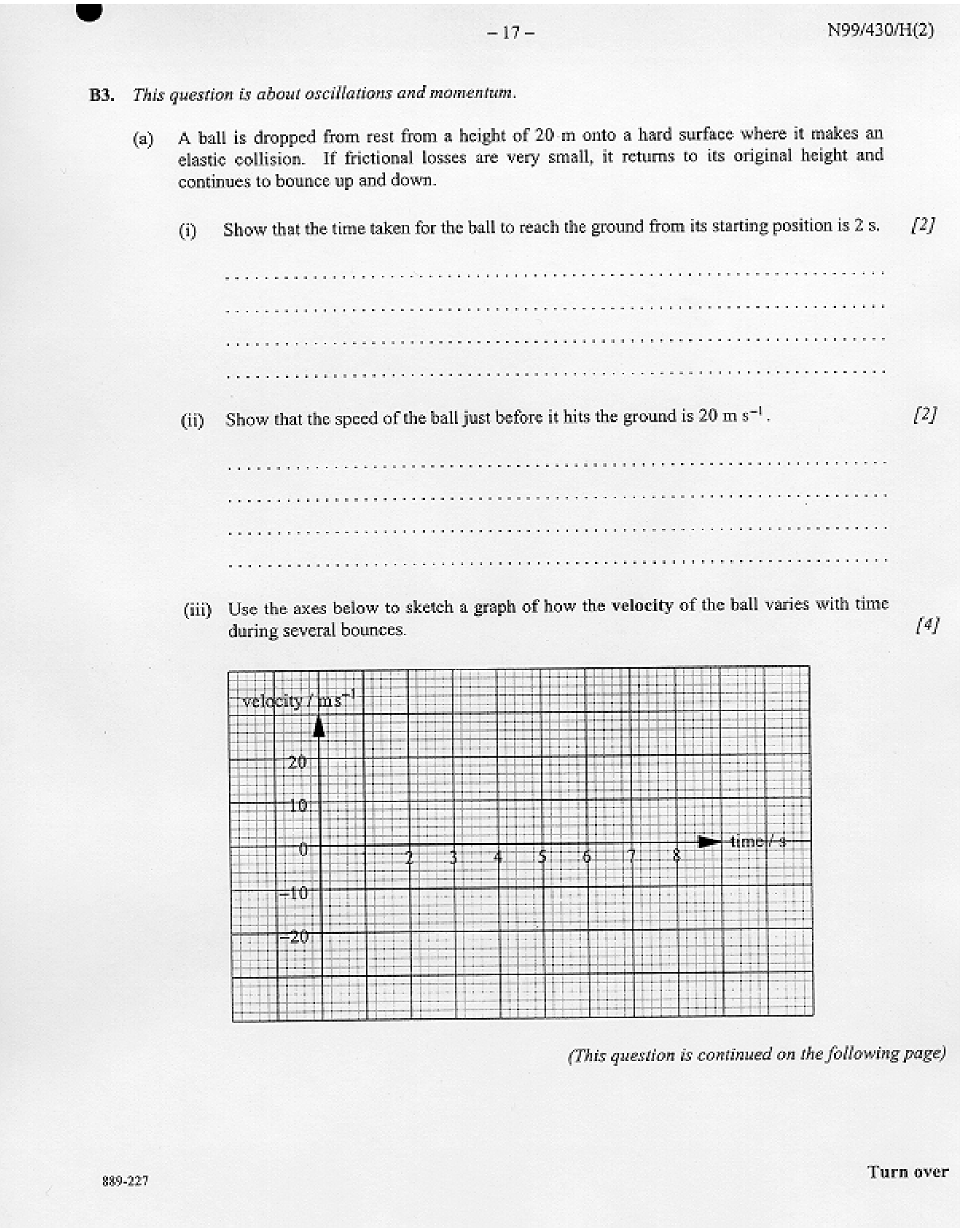
889-227 **Turn over**

FIGURE 3-5 November 1999 IB Physics HL, paper 2, question A2.
SOURCE: (IBO, 1999a)



– 17 – N99/430/H(2)

B3. *This question is about oscillations and momentum.*

(a) A ball is dropped from rest from a height of 20 m onto a hard surface where it makes an elastic collision. If frictional losses are very small, it returns to its original height and continues to bounce up and down.

(i) Show that the time taken for the ball to reach the ground from its starting position is 2 s. *[2]*

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(ii) Show that the speed of the ball just before it hits the ground is 20 m s^{-1}. *[2]*

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(iii) Use the axes below to sketch a graph of how the **velocity** of the ball varies with time during several bounces. *[4]*

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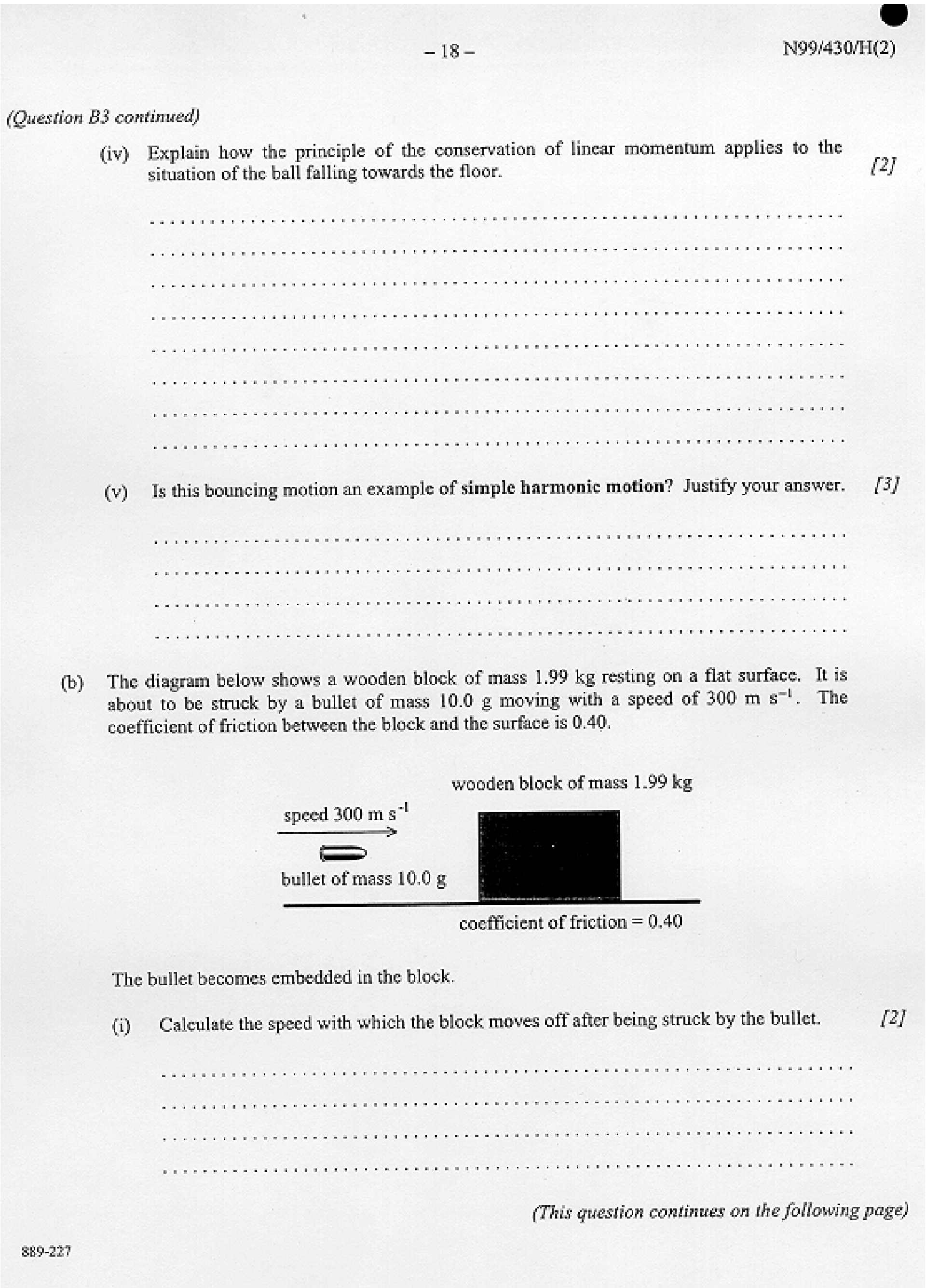
889-227

Turn over

FIGURE 3-6 November 1999 IB Physics HL, paper 2, question B3



(Question B3 continued)

(iv) Explain how the principle of the conservation of linear momentum applies to the situation of the ball falling towards the floor. *[2]*

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(v) Is this bouncing motion an example of **simple harmonic motion**? Justify your answer. *[3]*

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(b) The diagram below shows a wooden block of mass 1.99 kg resting on a flat surface. It is about to be struck by a bullet of mass 10.0 g moving with a speed of 300 m s^{-1}. The coefficient of friction between the block and the surface is 0.40.

The bullet becomes embedded in the block.

(i) Calculate the speed with which the block moves off after being struck by the bullet. *[2]*

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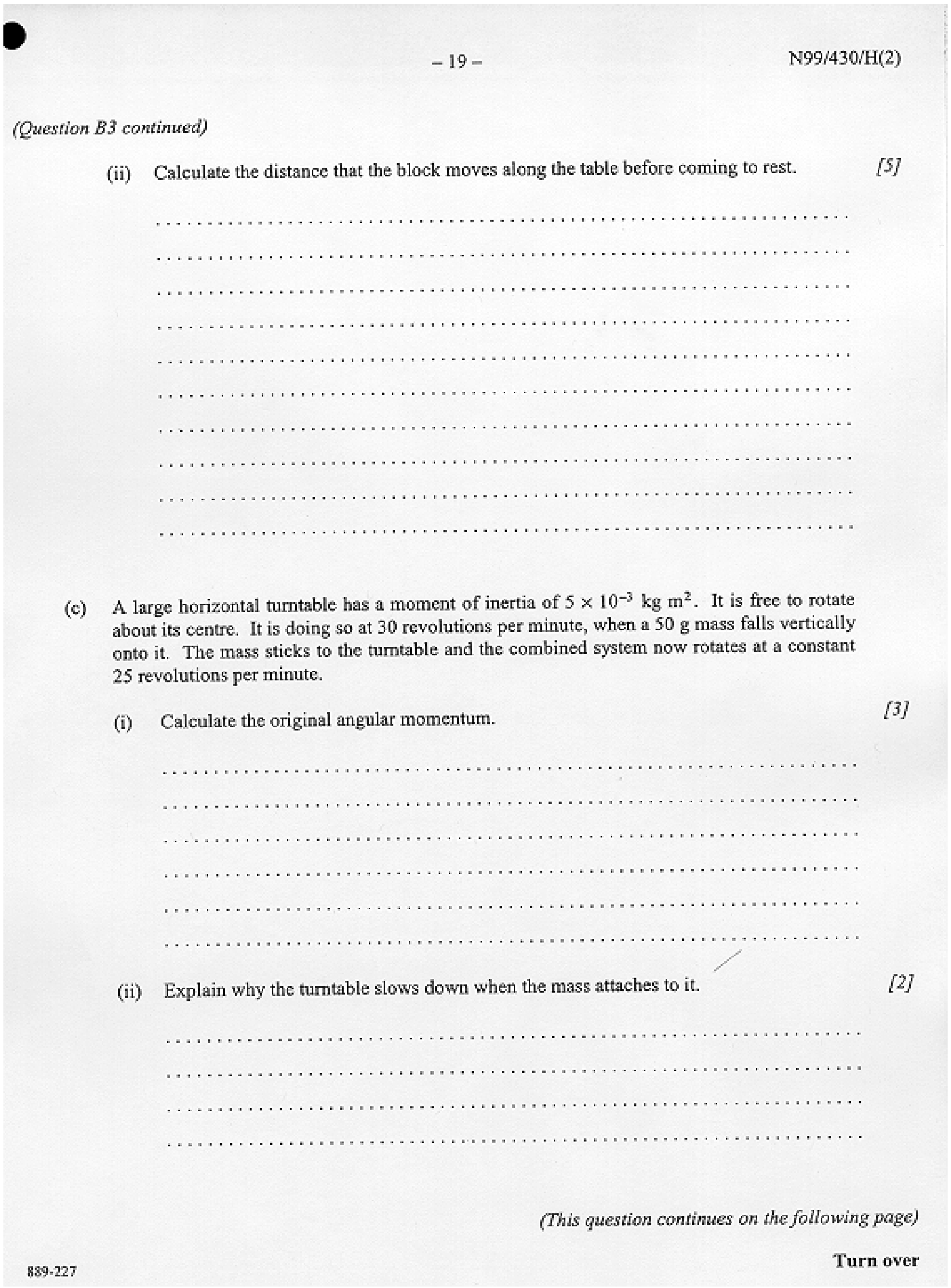
FIGURE 3-6 November 1999 IB Physics HL, paper 2, question B3 (continued)



(Question B3 continued)

(ii) Calculate the distance that the block moves along the table before coming to rest. *[5]*

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(c) A large horizontal turntable has a moment of inertia of 5×10^{-3} kg m^2. It is free to rotate about its centre. It is doing so at 30 revolutions per minute, when a 50 g mass falls vertically onto it. The mass sticks to the turntable and the combined system now rotates at a constant 25 revolutions per minute.

(i) Calculate the original angular momentum. *[3]*

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(ii) Explain why the turntable slows down when the mass attaches to it. *[2]*

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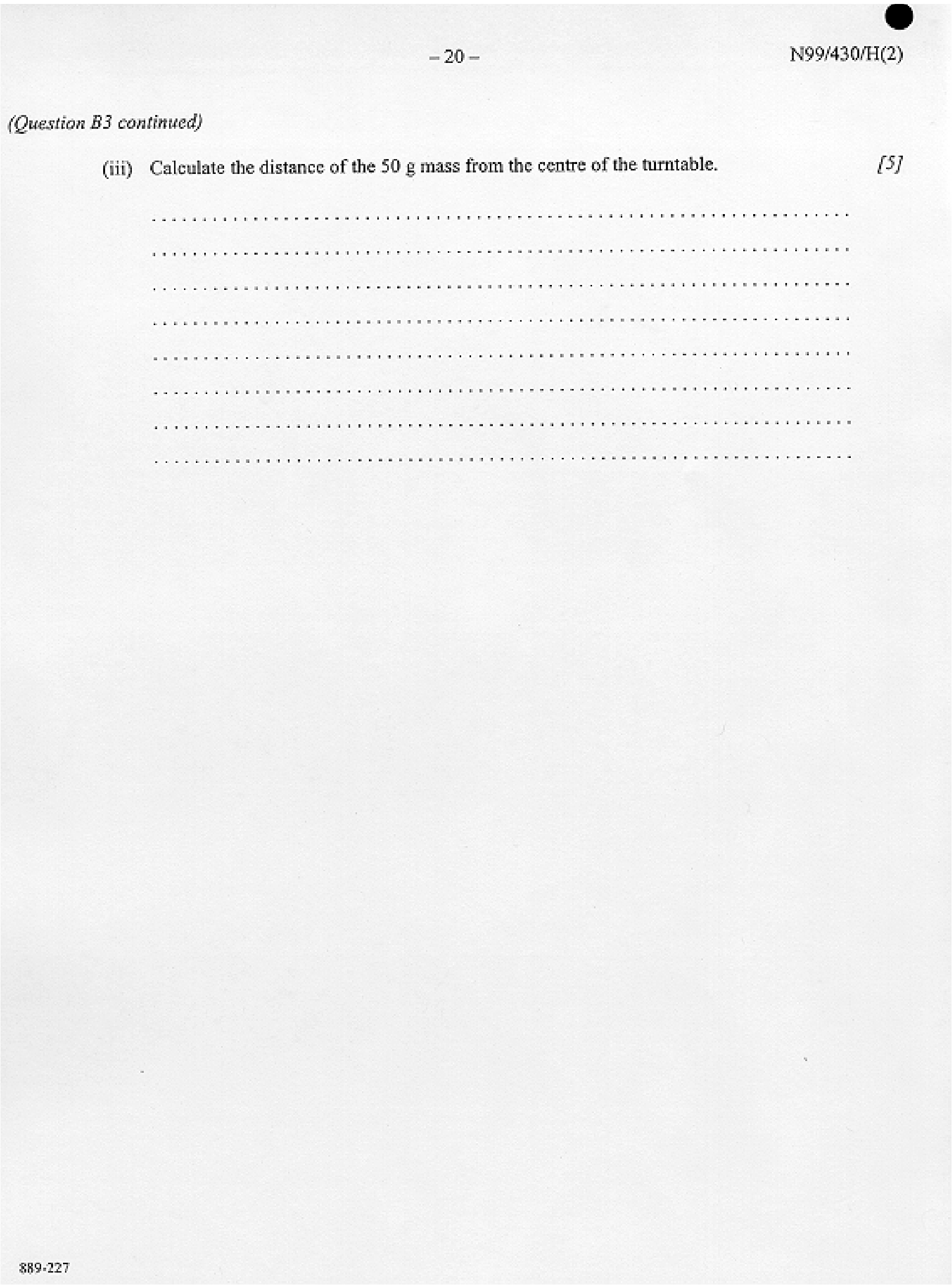
Turn over

FIGURE 3-6 November 1999 IB Physics HL, paper 2, question B3 (continued)



– 20 – N99/430/H(2)

(Question B3 continued)

(iii) Calculate the distance of the 50 g mass from the centre of the turntable. *[5]*

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889-227

FIGURE 3-6 November 1999 IB Physics HL, paper 2, question B3 (continued)
SOURCE: (IBO, 1999a)

- The IB curriculum's fixed minimum allocations of time to activities such as "practical investigative work" and the Group 4 project are somewhat troubling; it is far from clear that all the mandated activities are educationally worthwhile. Also, such fixed time allocations are in conflict with the teacher's need to adjust instructional strategy in response to a continually changing diagnosis of student understanding (see Chapter 4).
- The IB Physics course contains no calculus and therefore cannot delve as deeply as AP Physics C into electromagnetic theory.
- The IB physics examinations are more conceptually based than the AP physics examinations and give students sufficient time to think but suffer from many of the same faults of construction as the AP exams.
- Unlike the AP program, the IB program can assess laboratory skills by means of the internal assessment process.

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Teaching and Learning in Advanced Physics Programs

In the preceding chapters, advanced high school physics programs are discussed as if they can be separated from the particular teachers and students involved. Adopting this point of view greatly simplifies the discussion and makes it possible to draw some important conclusions. Nevertheless, the panel is convinced that the success of a given advanced high school physics program depends much more on the teachers and students than on the curriculum or other general program characteristics. We stress that in truth there is no such thing as *the* Advanced Placement (AP) physics program or *the* International Baccalaureate (IB) physics program. Rather, as noted earlier, the implementation of these programs varies widely from school to school and teacher to teacher, and these variations often have a much greater impact on the education of the students than the choice of which program to implement. In this chapter, we examine the characteristics of teachers and students that give rise to these critical variations in the implementations of AP and IB physics. Based on this examination, we offer several recommendations for improving the overall quality of advanced high school physics instruction.

THE TEACHERS OF AP AND IB PHYSICS

In the opinion of the panel, the most important factors in determining the quality of advanced physics instruction in high school are the talent and preparation of the teacher.[17] To achieve widespread high-quality advanced physics instruction, it is necessary to provide for both recruitment of highly qualified college students into the teaching profession and strong, substan-

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[17] The importance of the teacher is supported by objective evidence. When the Force Concept Inventory examination was given to the classes of teachers with poor preparation in physics and also to the teachers themselves, it was found that students' scores never exceeded the score of their teacher.

tive preservice and inservice professional development of physics teachers.[18]

Competitiveness of Salaries of Physics Teachers

While both beginning and average teachers' salaries have improved relative to inflation since the 1980s (Neuschatz and McFarling, 1999), the present competition for technical expertise makes salary an important factor in attracting new teachers to the profession. It is difficult to see how enough well-qualified college students can be attracted to the teaching of advanced physics courses when a similar amount of training would allow them to earn much higher salaries in other positions.

Low salaries not only make it difficult to attract people to the teaching profession but also lead to a general lack of respect for teachers. "If you could do something else, you wouldn't be here" is a far too common conclusion reached by students, parents, and others about the teachers they depend on for education.

Role of AP and IB Organizations in the Training and Credentialing of Teachers

At present, neither the AP nor the IB program requires any special credentials or teacher preparation for teaching its courses other than what is required by the school and the state in which the school is located. The IB program does require teachers to be trained in IB procedures when a school first joins the IB program; this initial training also includes a content work-

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[18] In May 1999, the Council of the American Physical Society adopted the following statement:

> AIP-Member Society Statement on the Education of Future Teachers: The scientific societies listed below urge the physics community, specifically physical science and engineering departments and their faculty members, to take an active role in improving the pre-service training of K–12 physics/science teachers. Improving teacher training involves building cooperative working relationships between physicists in universities and colleges and the individuals and groups involved in teaching physics to K-12 students. Strengthening the science education of future teachers addresses the pressing national need for improving K–12 physics education and recognizes that these teachers play a critical education role as the first and often-times last physics teacher for most students. While this responsibility can be manifested in many ways, research indicates that effective pre-service teacher education involves hands-on, laboratory-based learning. Good science and mathematics education will help create a scientifically literate public, capable of making informed decisions on public policy involving scientific matters. A strong K–12 physics education is also the first step in producing the next generation of researchers, innovators, and technical workers (http://www.aps.org/statements/99.1.html [4/17/2002]).

shop for teachers. In addition, the IB program provides numerous optional content workshops for IB physics teachers at locations around the world.

A number of institutions offer 1- or 2-day AP workshops or summer institutes, but these are not required of teachers offering AP courses. The panel suggests that the College Board and the International Baccalaureate Organisation (IBO) consider whether requiring such workshops or introducing some form of mandatory or optional credentialing would improve the quality of preparation of teachers of their programs.

A recent American Institute of Physics survey (Neuschatz and McFarling, 1999) notes that about one-third of high school physics teachers have a degree in physics or physics education, and an additional one-sixth have a minor in physics. Almost all the rest have degrees either in another science or in mathematics. Many report being inadequately trained to use computers in the laboratory and the classroom, and only half report taking part in any physics workshop, meeting, or course during the year preceding the survey. The panel believes such training deficiencies are a major cause of unsuccessful outcomes in advanced physics teaching.

Involvement of College and University Physics and Engineering Faculty in the Training of Teachers of Advanced High School Physics

The *National Science Education Standards* (National Research Council [NRC], 1996) contain detailed standards for the professional development of science teachers. The panel urges the cooperation of the entire physics community in the recruitment and training of physics teachers who meet those standards. In particular, we join the American Institute of Physics, the American Physical Society, the American Association of Physics Teachers, and other physics organizations in calling on college physics and engineering faculty to take an active role in the training of teachers for advanced high school physics programs.[19]

The panel concurs with the opinion of Robert Watson, director of the Division of Undergraduate Education at the National Science Foundation, that if science departments in colleges and universities were more hospitable to students who wanted to become teachers, not only would those students be better prepared to go into teaching but a much stronger cadre of students would be attracted to teaching (NRC, 1997a, p. 4). Physics departments need to treat high school physics teaching as an honorable specialization for an undergraduate physics major and provide both undergraduate

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[19] See the December 1999 *Statement on the Education of Future Teachers* at www.AIP.org.

and graduate courses of study aimed at the preparation and continued professional development of skilled physics teachers.

Physics departments should pose the prospect of high school teaching as an option in advising students, perhaps in conjunction with a local physics teacher who could provide perspective on such a career choice. Physics majors specializing in education should take the same foundational courses as conventional physics majors, replacing some elective or specialized coursework with courses of similar rigor that probe in depth the problems of learning and teaching physics. Such courses should include the use of traditional techniques, as well as modern teaching techniques based on research on physics education. Recognizing that a substantial fraction of all undergraduate physics majors will end up instructing others in some fashion at some time in their careers, a course in teaching and learning would be a useful addition to the physics major in general, although the details of such a course would vary. The panel notes that some programs of this type are already in operation (see, for example, Roelofs, 1997).

Preparation Needed to Teach Advanced Physics Courses Effectively

There is no doubt that to teach advanced physics effectively a strong background in physics content is absolutely essential. Teachers who do not understand the subject themselves cannot possibly develop deep conceptual understanding of physical principles in their students.

However, a thorough understanding of the subject matter is not sufficient. A teacher must also be skilled in the specialized pedagogy of physics. Physics teachers need to be trained to understand their students' view of the physical world (which is often radically different from that of physicists) and adjust their teaching techniques accordingly (as discussed below).

EFFECTIVE TEACHING IN ADVANCED PHYSICS PROGRAMS

Another reason for the varying degrees of success among teachers is that different teachers teach in different ways. A great deal of research has been done to identify the most and least effective teaching practices for educating students of science. In this section, we summarize the main results of that research from the point of view of advanced physics instruction.

Findings of Research on *How People Learn*

A number of summaries of the implications of recent research on learning for the teaching of science have been prepared. The panel notes and endorses the NRC (2000) report *How People Learn: Brain, Mind, Experience, and School: Expanded Edition*. Adapting and elaborating these findings specifically for the study of physics leads to the following implications for effective instruction.

1. Teachers must draw out and work with students' current understandings, including those students bring with them to the course and those they develop as the course progresses.

There is a robust consensus in education research, including a substantial body of work specific to introductory physics (Champagne, Gunstone, and Klopfer, 1985; Clement, 1982; Hake, 1998; Hestenes, Wells, and Swackhamer, 1992; McDermott and Redish, 1999), that to be effective, instruction must elicit, engage, and respond substantively to student understandings. There are now a number of examples of curricula and materials designed to support productive interaction with student understandings (as discussed later in this chapter), and there is evidence that these approaches can achieve progress in understanding not possible for most students with traditional methods.

2. Teachers must address students' metacognitive skills, habits, and epistemologies.

Students need to understand not only the concepts of physics but also the nature of knowledge and learning (Halloun, 1998; Hammer, 1995; Hewson, 1985; McDermott, 1991; Redish, Steinberg, and Saul, 1998; Reif and Larkin, 1991; White and Frederiksen, 1998). Many students arrive at physics courses, including advanced courses, expecting to learn by memorizing formulas disconnected from each other, as well as from the students' experiences of the physical world. Effective instruction challenges these expectations, helping students come to see physics learning as a matter of applying and refining their current understanding. Students must learn to identify and examine assumptions hidden in their reasoning; to monitor the quality and consistency of their understanding; to formulate, implement, critique, and refine models of physical phenomena; and to make use of a spectrum of appropriate representational tools. By the end of an advanced course, students should have developed a rich sense of the coherent, principled structure of physics and be both able and inclined to apply those principles in unfamiliar situations. In short, effective instruction should work toward the objectives identified in Chapter 2.

Many teachers start off well by explaining to their students that success in studying physics depends on learning and applying general principles, rather than on memorizing many unrelated facts and formulas. Talk, however, is cheap. Too many teachers follow up these commendable words by evaluating their students on the basis of their skill in solving problems that are handled most efficiently by just such memorization. Teachers must design the assessments in their courses to make the statement that "success depends on learning and applying general principles" a reality.

3. Effective teachers are sophisticated diagnosticians of student knowledge, reasoning, and participation.

How teachers respond to student thinking depends critically on what they perceive in that thinking, on what they interpret to be the strengths and weaknesses of the student's understanding and approach.[20] Effective teachers continually gather information to support this ongoing assessment from several different sources: written work on assignments, tests and quizzes, classroom discussions, and contact with students outside the classroom. They ask students to explain their reasoning throughout their work. Upon gaining new insights into student understanding, effective teachers adapt their instructional strategies and objectives. For this reason, teachers must be trained both to make accurate diagnoses of student thinking and to devise effective responses to that thinking (as discussed earlier).

4. Teachers must teach a smaller number of topics in greater depth, providing many examples in which the same concept is at work.

This is a common refrain in findings from education research, often expressed in the slogan "less is more." In part, this precept is an implication of the previous two: drawing out and working with student understandings and addressing metacognitive skills and habits all take time, and this necessitates a reduction in the breadth of coverage. Education research also yields the robust finding that coming to understand a concept requires multiple encounters in multiple contexts. This finding is reflected across innovations in physics curricula (see the discussion later in this chapter).

A related consideration is that effective teaching requires limiting class sizes to a reasonable number. Drawing out, evaluating, and working to improve student understandings is a highly individualized process that is nearly impossible to perform adequately in oversized classes.

These admonitions from education research are not controversial, but their generality may allow multiple, superficial, and possibly conflicting in-

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[20] For an extended discussion and example of diagnosis in a high school physics class, see Hammer (1997). For an account of facets-based diagnosis, see Minstrell (2000). Diagnoser, a software tool designed to support facets-based diagnosis of student thinking, is available at http://depts.washington.edu/huntlab/diagnoser [4/23/02].

terpretations. If these points are to be meaningful, it is essential that they be discussed with respect to specific instances of learning and instruction (examples include Minstrell, 1989; Hammer, 1997; Roth and Lucas, 1997; and van Zee and Minstrell, 1997).

Special Considerations in Advanced Physics Instruction

The panel acknowledges that there are students who are successful at learning under almost any circumstances, that these students often appear in advanced courses, and that for them the implications of the previous section may not be as critical. However, such students do not appear to constitute the majority of those enrolled in advanced courses. Moreover, even the best students would benefit from the recommendations of the research discussed above.

With these considerations in mind, the panel's first concern regarding advanced courses is that the breadth of the curriculum often leaves very little time to do anything but introduce new subject matter. Therefore, a serious attempt to improve instructional practices will require giving up coverage of some material. The panel's recommendations for accomplishing this are presented in Chapter 2.

The panel's second concern is that the emphasis in advanced courses on solving typical textbook problems as opposed to conceptual discussion and debate tends to encourage rather than challenge student perceptions that physics knowledge comprises disconnected factual units rather than a principled system of ideas. Although skill in problem solving is an important objective of any advanced physics program, conceptual understanding must be the objective of highest priority.

Extent to Which the AP and IB Curricula and Assessments Encourage Teachers to Use a Variety of Teaching Techniques

As described in Chapter 3, the College Board leaves the way in which AP physics is taught entirely to the particular implementation of AP physics in each school. There are no requirements that must be met before students can take the AP examinations. Although the College Board does offer advice to teachers in various publications, it is entirely up to the particular school whether to accept or reject that advice. The only means the College Board has of encouraging teachers to use a variety of techniques is through the construction of the examinations. Recent examinations have tended to emphasize conceptual understanding and real-world situations to a greater degree than earlier examinations. To the extent that a variety of teaching techniques is necessary to prepare students to answer these kinds of questions, the use of such varying techniques is encouraged.

In contrast, the IBO spells out in great detail the time to be spent doing different kinds of activities in IB physics courses. For example, 25 percent of instructional time is to be spent by students pursuing a program of "practical work" (see Chapter 3). Moreover, a great deal of written material is available to IB teachers containing detailed suggestions for carrying out these activities. Thus the IBO most definitely encourages the use of a variety of teaching techniques and in fact goes a long way toward mandating the use of such a variety.

Whether the use of that variety is effective in the IB program, however, is entirely another matter. As discussed earlier, teachers need to be free to adjust their teaching techniques and objectives as they continually diagnose the state of understanding of their students. The IB program's prescriptions of time to be spent in various activities may deprive teachers of the flexibility they need. The panel is skeptical that such inflexible prescriptions are appropriate for advanced physics instruction.

The panel has been informed through personal testimony and anecdotal evidence that some experienced IB physics teachers do not feel constrained to follow these time prescriptions. The panel considers the full use of whatever flexibility is available to be entirely appropriate.

Differences Between High School Physics Instruction in the United States and Other Countries

In light of the poor performance of U.S. students on the physics portion of the Third International Mathematics and Science Study (TIMSS) as compared with students from other developed countries (see National Center for Education Statistics, 1998), certain characteristics of the U.S. physics education program need serious reconsideration and further study. To be clear, the panel is not endorsing TIMSS as the way to measure success in physics education; rather, we believe the lower scores of American students are a good reason to explore what can be learned from the methods of physics instruction used in other TIMSS countries.

Perhaps the most obvious difference between physics instruction in the United States and other countries is the number of secondary school years devoted to physics study. In most TIMSS countries, students develop their physics knowledge over a period of many years, rather than the traditional 1 year commonly offered in the United States. The system used by other countries appears to be more consistent with the findings of education research that coming to understand a concept requires multiple encounters in multiple contexts.

One possibility for American programs to consider is moving the single year to a different position in the traditional "layer-cake sequence." Doing so might change the mathematical level at which physics is taught or might involve students at a different stage of cognitive development. It might also facilitate the use of physics in interdisciplinary high school science classes such as those encompassing biology and physics.

Another alternative is to offer physics along with other scientific disciplines in an integrated or coordinated course for the first 2 years of high school and then offer further physics study in the junior or senior year at an advanced level. This approach is similar to that of science programs in most comparison countries. Additional years of integrated science courses in the third and fourth high school years is another possibility. Given the scarcity of comparison data on these sequences and the fact that many schools in the United States are making the transition to integrated courses as a result of exciting new curricular offerings, this is an excellent time to examine these issues.

A second significant area of difference between physics instruction in the United States and other TIMSS countries lies in the recruiting, training, professional development, and status of physics teachers. The salary situation for American secondary school physics teachers is particularly troubling (as noted earlier). First, the difference in salary between positions attainable by physics majors (e.g., computer programmer, laboratory technician) and the position of beginning teacher is much greater in the United States than in most comparison countries. Second, the comparison with professions unrelated to physics is no better. In Japan, for example, secondary school teachers are in the top 20 percent of the professional salary scale; in the United States, they are in the bottom 20 percent. Salary issues related to recruitment and retention need to be addressed for the U.S. physics teaching profession before we find ourselves with far too few qualified teachers or mentors.

A third area of difference is reflected in the fact that some of the TIMSS content involves topics not commonly covered in U.S. physics courses. One example, thermodynamics, not only is poorly understood by many physics teachers and therefore avoided but also is often left to chemistry teachers as a part of their curriculum. Although the United States is generally perceived to teach more science topics in less depth than is the case in other countries, physics topics beyond mechanics and electricity and magnetism are often mentioned in a highly perfunctory fashion. U.S. students may well have no experience with these topics, especially on exams. Other examples are the lack of emphasis on statistics and statistical analysis and the lower factual content in U.S. textbooks compared with many European high school texts. More data are needed to determine whether these and other mismatches put U.S. students at a disadvantage.

U.S. students also appear to spend more class time doing laboratory work and to do more independent work than their counterparts in other countries. Although many believe these uses of student time encourage the development of creative, bold, and imaginative physicists, the time spent in the laboratory may diminish that devoted to other physics class activities, such as problem solving, which may in turn affect test scores.[21]

Finally, unlike the United States, many comparison countries have extensive evaluation and assessment programs. Since most foreign countries have national educational assessments, their evaluation processes may be more efficient and meaningful in such disciplines as physics. Some programs have been in place for at least 100 years, involve highly trained teachers as external graders, and publish school scores publicly. The availability of long-term student assessment data may be an important factor leading to the educational success of those programs.

THE STUDENTS OF AP AND IB PHYSICS

This section examines how the nature of the student body affects educational outcomes in advanced physics instruction. The students who take AP and IB physics courses come from a wide variety of academic, cultural, and socioeconomic backgrounds. This diversity can only increase as both programs continue to expand in size. An effective implementation of AP or IB physics must take into account the background of the students enrolled in that particular implementation.

The Problem of Widely Varying Levels of Academic Preparation and Ability

Variations in abilities and preparation levels make teaching an advanced physics program more difficult for both teacher and students. When the ability or preparation of some students is far below the expected prerequisite level for advanced study, the teacher is faced with the unenviable choice of either decreasing the extent or depth of content coverage to accommodate those poorly prepared students, thereby failing to meet the needs of the students who are adequately prepared; or teaching the course at the level appropriate for the adequately prepared students, thereby failing to meet the needs of those who are poorly prepared.

The panel wishes to emphasize that preparation must include more than background knowledge and related skills. It must also include the develop-

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[21] This observation is offered only as a possible contributing factor to the low TIMSS scores of American students. Naturally, we are far more interested in developing creative scientists than in catching up on test scores.

ment of mature work habits. Students who do not complete their homework or are generally unwilling or unable to put forth sustained high levels of effort are unlikely to succeed in advanced physics study in high school and may have effects on other students' learning that cannot be ignored.

It is not possible to avoid inappropriate placement situations entirely—nor would doing so be desirable. Students who want to try a difficult course because they are genuinely interested should be encouraged to do so, provided they are made fully aware of the commitment of time and effort they are about to make. For some of these students, a well-taught and challenging advanced course in physics could spark learning and interest that had previously gone unrecognized. On the other hand, seriously underqualified students should be discouraged from taking advanced physics. Doing poorly in a course for which a student is not prepared often discourages the student from further study in the field and certainly will not enhance his or her application to college.

These are complex issues with no easy solutions, and we recognize that not everyone will share our views. The panel recommends discretion in the assignment of students to advanced courses,[22] so that the teacher is able to maintain the integrity of the course as an advanced treatment of the concepts being covered. For example, in solving projectile motion problems, a comprehensive treatment is commonly not accessible to some fraction of the class simply because they do not know how to solve quadratic equations. The panel believes appropriate members of each school's staff should be involved in decisions about admitting individual students to the school's advanced physics program. Of course, the school staff should consult with students and their parents and consider their views carefully in the deliberations, as appropriate. School personnel, students, and parents should be clear about what constitutes adequate preparation for an advanced physics program. Such preparation might include background knowledge and related skills, such as mature work habits.

At first glance, it may appear most fair to deny admission to underprepared students. However, many students lack the necessary preparation because of limited educational opportunities beyond their control. Moreover, as noted above, some of these students may experience an academic awakening when provided with such opportunities. The panel believes it is the job of the school staff to identify those underprepared students who are likely candidates for such experiences and admit them to the advanced physics program regardless of prerequisites. Doing so may require extensive interviews with

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[22] Normally, this discretion is exercised by the school administration. The standards set by the administration should reflect the best interests of the students in that particular school. The panel believes failure to exercise such discretion can make it impossible to run a successful advanced physics program.

the student, the student's parents and teachers, and others who know the student well. Making these judgments is not easy, but we believe it is within the capability of a skilled educational staff.

Ultimately, the way to expand access to advanced physics is to reform the education system so that all students will be able to experience a rigorous academic program that will allow them to study advanced physics in their late high school years if they choose to do so.

Role Played by the Culture of the American High School

Students do not take advanced physics in a vacuum. They are constantly interacting with the surrounding high school environment, which places substantial demands on them physically, intellectually, socially, and morally. Since the study of advanced physics is itself a demanding pursuit, there is a constant struggle between the advanced physics program and other activities for the attention of students. To be successful, an advanced physics program must adapt itself to the particular high school environment and find a way to use whatever time students can devote to the program to best educational advantage.

Competing activities that place demands on the time of advanced physics students include part-time employment; athletics; community service; music and drama; college visits; television and movies; computer activities, including Web surfing; family vacations; and social events. Much of the pressure to engage in these activities comes from colleges and universities. In a desire to enhance their college applications, students often undertake an enormous variety of activities that leave them too little time for their studies. Pulled in so many directions at the same time, these students have a low attention span, both in class and in doing their homework.

It must also be recognized that English is not always the native language of advanced physics students. Since the concepts of advanced physics are new and difficult for many students, a poor command of English can cause serious problems for those who are otherwise quite well prepared for the course. Even for native English speakers, the specialized use of common words such as *momentum* or *work* often leads to confusion. Those effects are exacerbated among students for whom English is a second language. In addition, cultural influences can affect how students think about science: reasoning by analogy or by strict linear logic; memorization of specific correct responses or generalization; problem solving by induction or by deduction; or needing to learn through hands-on apprenticeship to gain one aspect of a skill before moving on to the next step (Kolodny, 1991). Cultural prohibitions permeate some societies; for example, values that discourage assertiveness, outspokenness, and competitiveness in some cultures result in behavior that can be interpreted as being indifferent, having nothing to say, or being unable to act decisively (Hoy, 1993; NRC, 1997b, p. 59). The problems engendered by these cultural differences are often beyond the ability of teachers of advanced courses to handle on their own. In many such cases, support from other members of the school staff is essential.

Finally, we note that advanced programs should use the resources of the community to maximum advantage. In many cases, local corporations are willing to make substantial contributions of equipment for the use of advanced physics programs. They also often run special programs and competitions that are highly stimulating to advanced students. Government laboratories and colleges can have a large positive impact on advanced programs as well by giving students the opportunity to meet practicing scientists and explore laboratories in which research at the forefront of physics is taking place. Teachers of advanced courses should avail themselves of these special opportunities in their communities.

ALTERNATIVE CURRICULAR MATERIALS FOR ADVANCED PHYSICS INSTRUCTION

Many excellent advanced physics courses can be developed using traditional physics texts because a skilled teacher can modify the material to incorporate interactive engagement techniques (Hake, 1998) that enhance student learning. It would be better, however, to have curricular materials that directly support interactive engagement. This section describes several examples of such materials to demonstrate the variety of alternative resources available and to provide some concrete examples of what is meant by interactive engagement. The panel makes no claim of completeness in our listing, nor are we endorsing any particular set of materials.[23]

Most of the following materials have been developed and studied by researchers in physics education. In several cases, there is a significant body of evidence of improvements in student learning:[24]

- *Real Time Physics* (Sokoloff, Laws, and Thornton, 1994, 1997) is a guide to microcomputer-based laboratory work designed to enhance stu-

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[23] More information about the materials, along with links to the publishers, can be found at the Web site of the American Association of Physics Teachers' Physical Sciences Resource Center, www.psrc-online.org [4/17/02]. Many of the publishers maintain Web sites of resource materials that may be useful to teachers.

[24] This evidence is not specific to advanced high school physics courses. However, it is reasonable to expect that results from introductory college-level courses should generally apply.

dents' conceptual understanding of introductory physics topics. Studies of students using these materials have shown marked improvements in their understanding of concepts of kinematics and dynamics (Thornton and Sokoloff, 1990, 1998).

- "Physics Tutorials" (McDermott and Shaffer, 2002) are a combination of written exercises and simple experiments that can enhance student understanding of introductory physics topics. Designed primarily for use in introductory college courses to supplement conventional curricula, these tutorials would be appropriate and valuable for use in advanced secondary courses. The most complete set of such materials is that of the University of Washington Physics Education Group (McDermott, Shaffer, and Somers, 1994; Shaffer and McDermott, 1992; and Wosilait, Heron, Shaffer, and McDermott, 1999).
- *A Modeling Method for High-School Physics Instruction* (Wells, Hestenes, and Swackhamer, 1995) focuses on having students actively engaged in defining, building, understanding, and testing mathematical models of physical phenomena. Students compare their models with both traditional models and the results of experiments. The method focuses on model building, testing, and deployment (using the model in new situations) as a key scientific activity (Halloun, 1996).
- The *Workshop Physics Activity Guide* (Laws, 1997) is used as the main text for a 1-year calculus-based physics course (a traditional physics text can be used as a reference). The course features the use of integrated computer tools that students, working in small groups, use to collect, display, and analyze data and to develop mathematical models describing physical phenomena. Based on the results of physics education research, the guide uses a four-part learning cycle to have students (1) predict the results of an experiment, (2) reflect on the actual results and refine their predictions, (3) develop mathematical models with appropriate equations to describe the experiment, and (4) perform experiments to test the models (Laws, 1989, 1991, 1999).
- *Electric and Magnetic Interactions* (Chabay and Sherwood, 1999) is a calculus-based introductory physics course that emphasizes the development of conceptual models and scientific explanations of electricity and magnetism phenomena. Kits of scotch tape, batteries, lightbulbs, one-farad capacitors, and so on are used for "desk-top experiments" that introduce phenomena before students build detailed mathematical and conceptual models. The authors are just completing a text, *Matter and Interactions* (2002), to be used in the first semester of an introductory physics course. That text also emphasizes conceptual models and scientific explanations reinforced by computational studies of mechanical systems.
- *Six Ideas That Shaped Physics* (Moore, 1998) is a calculus-based course that organizes physics topics around six big ideas. Each chapter includes

many conceptual questions useful for in-class engagement, as well as a good collection of physics problems that require students to synthesize topics. The latter are particularly useful for collaborative learning groups. The book includes a good introduction to relativity, a section on quantum mechanics, and a section on thermal physics emphasizing a statistical mechanics approach. Early versions of the text were evaluated through the Introductory University Physics Program.[25]

- *Physics: A Contemporary Perspective* (Knight, 1997) claims to be the first complete calculus-based introductory physics textbook reflecting the results of physics education research. It emphasizes a balance of qualitative and quantitative reasoning, multiple representations of knowledge, and a systematic approach to problem solving. A companion student workbook helps students develop conceptual and graphical understanding.
- The *CASTLE* curriculum materials developed by Pasco Scientific include material for investigating electricity, including batteries, lightbulbs, compass needles, and large capacitance capacitors. The focus is on developing conceptual models of electrical effects, particularly in circuits.[26]
- *C3P: Comprehensive Conceptual Curriculum for Physics* is a high school curriculum that draws on materials from a variety of sources, including videos, inquiry methods, and laboratory experiments.[27]
- Although not traditionally part of advanced physics courses in high schools, quantum physics may well be used as an optional or enrichment topic. A set of materials called *Visual Quantum Mechanics* has been developed by Dean Zollman and colleagues in the Kansas State physics education research group. The materials include simple experiments that illustrate basic quantum physics phenomena using light-emitting diodes, glow sticks, and other inexpensive equipment. Computer programs help students build conceptual models to explain the results of the experiments.
- Several publishers are revising traditional textbooks to take into account the results of physics education research. These revised texts emphasize student engagement in developing conceptual understanding, as well as improved approaches to problem solving. Already published is *Physics for Scientists and Engineers* (Serway and Beichner, 2000). In addition, a team of physics education researchers is producing a new version of *Fundamentals of Physics* (Halliday, Resnick, and Walker, 2000). This version is still in progress and should not be confused with the sixth edition of the textbook released in July 2000.
- Some other resources that might be used in an advanced high school physics course include the following:

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[25] A report on these evaluations can be found in Coleman, Holcomb, and Rigden (1998).

[26] More information can be found on the Web at http://www.pasco.com [4/17/2002].

[27] For further information, see the Web site http://phys.udallas.edu [4/17/2002].

–*PRISMS (Physics Resources and Instructional Strategies for Motivating Students)*—The primary materials include a teacher's guide with 120 activities for use with introductory physics students.[28]

–PTRA Workshops and Manuals—The Physics Teacher Resource Agents program (sponsored by the American Association of Physics Teachers and the National Science Foundation) has developed a series of workshops and teacher resources for most of the topics taught in high school physics. The majority involve hands-on projects for students, as well as other teaching materials.[29]

–*String and Sticky Tape Experiments* (Edge, 1987).

–*Conceptual Physics* (Hewitt, 1999).

–*Active Physics* (Eisenkraft, 1999)—This text is designed to be used as a "physics first" course, where students in ninth or tenth grade take physics before chemistry or biology. All of the units focus on applications of physics in everyday life, such as automobiles, home heating, and sound reproduction, with many hands-on activities.

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[28] Further information is available at http://www.prisms.uni.edu [4/17/2002].

[29] Further information can be found at the American Association of Physics Teachers Web site by going to http://www.aapt.org [4/17/2002] and clicking on Programs and then PTRA.

5

Changing Emphases in Physics and Their Impact on Advanced Physics Instruction

The panel notes two changes in the practice of physics that should eventually be reflected in instruction in advanced physics courses in high school: the increasing use of computers in a variety of ways and a growing emphasis on interdisciplinary connections.

INCREASING USE OF COMPUTERS

The availability of easy-to-use numerical computation tools, graphical analysis programs, symbolic manipulation programs (e.g., MathCad, MAPLE, Mathematica), computer-based data acquisition, simulation programs, and the like is leading to dramatic changes in the practice of research in physics. As a result, there is somewhat less emphasis on detailed analytic calculations in many areas of physics research and an explosion of work in such areas as nonlinear dynamics and the study of complex systems, in which numerical and graphical tools are absolutely essential because traditional analytic methods fail. The panel argues that these same tools have the potential to effect major changes in the nature of introductory physics instruction.

The beginnings of those changes can be seen in the widespread use of computer-based and calculator-based data acquisition in introductory physics laboratory work. Computer simulations are also beginning to be used as a way of allowing students to explore actively the predictions and range of validity of various models of the physical world. These tools help introductory physics students build a better conceptual understanding of physical phenomena by actively exploring models and their predictions. Finally, and most provocatively, researchers have begun to pursue the use of computer programming as a medium and language for the study of introductory physics. In a manner that reflects the growing role of computational modeling in physics research, students may benefit by using computer programming as a means to express, explore, and refine ideas in physics (diSessa, 2000; Sherin, diSessa, and Hammer, 1993; Wilensky and Resnick, 1999).

The panel sees little in the current Advanced Placement (AP) and International Baccalaureate (IB) curricula that reflects these changes in the practice of physics. We note that although many AP and IB teachers do make use of computers in a variety of ways, neither the AP nor the IB examination assesses the use of computer tools. Accordingly, the panel makes the following recommendations:

- Advanced high school physics curricula should, over a period of time, evolve to include more use of computer tools in ways that are effective in physics instruction.
- Physics education researchers and others should continue to study the use of computers in introductory physics instruction (including advanced high school courses) to identify those uses that are particularly effective in promoting the instructional goals identified elsewhere in this report.

Eventually, cyberspace and information technology (CIT) may completely change the way new physical theories are developed. Instead of analytical models, theorists will use computer programs to conceptualize physical systems that cannot be adequately represented by traditional analytical methods. Students need exposure to such computer-assisted conceptualization as early as possible in their education. Therefore, the panel recommends that an appropriate unit in computer-assisted conceptualization be developed as soon as possible and made available to teachers of advanced physics courses as a possible optional topic (see Chapter 2 for a discussion of optional topics).

Capability for Rapid Information Sharing Among Physics Teachers

The primary opportunity afforded by the ever-expanding Internet is its promise of a new method of communication by which groups focused on particular sets of issues can rapidly interact to develop innovations. Teachers of advanced high school physics courses could form such groups to share and enrich their pedagogical skills. The opportunity now exists to create a national electronic clearinghouse of information relating to secondary school physics instruction. Box 5-1 presents a short list of some Internet groups that are already active.

Introducing Students to the Benefits of the Internet

Teachers of advanced high school physics are ideally positioned to introduce their students to the use of the Web and cyberspace technologies for carrying out research. Thus, the training of more computer-savvy profes-

BOX 5-1 Internet Groups for Physics Teachers

The following are some active Internet groups for physics teachers. The descriptions of these groups are taken from the article "Communities of On-Line Physics Educators" by Dan MacIsaac (2000):

- PHYS-L (Forum for Physics Teachers) is the largest with about 650 members and has the broadest membership. The list has a homepage located at http://purcell.phy.nau.edu, and this page links to archives of all postings since February 1996 and to list members' personal Web pages at http://members.xoom.com/exit60. Together these form an outstanding set of resources.
- PHYSHARE (Sharing Resources for HS Physics Teachers) has about 600 subscribers and focuses on high school physics teaching issues. The list administrative address is listserv@lists.psu.edu, and postings must be made to physhare@lists.psu.edu.
- PhysLrnR (Physics Learning Research List) has about 475 subscribers and is focused on professional research into physics learning. This list maintains a private archive for postings, accessible to subscribers only. PhysLrnR maintains a large collection of specialist literature on Physics Education Research (PER) on an ftp server at ftp://physlrnr.idbsu.edu/plrserve/pub/physlrnr. The list administrative (or control) address is listserv@listserv.boisestate.edu, and postings must be made to PhysLrnR@listserv.boisestate.edu.
- TAP-L is a smaller list specializing in design and construction of physics laboratory and demonstration apparatus. Members are mainly college and university physics department demonstration and lab coordinators, and PIRA (Physics Instructional Resource Association) members. Postings are archived since 1999, and there is a list Web page at http://members.odyssey1.net/kctipton/tapfaq.html. Uniquely, this list runs a web ring of web sites run by the demonstration and laboratory coordinators at several dozen universities and colleges. The list administrative (or control) address is listproc@listproc.appstate.edu, and postings must be made to tap-l@listserv.appstate.edu.
- AP-PHYSICS is a list run by the College Board specializing in the teaching of AP Physics. Information on subscribing is available on the College Board's website at http://www.collegeboard.org/ap/listserv/list.html.

SOURCE: Adapted from MacIsaac (2000). Also available on the Internet as a pdf file: http://purcell.phy.nau.edu/phys-l/TPTApr00art.pdf [4/23/02].

sionals could be naturally encouraged within advanced physics programs. If this is to occur, of course, computers will have to be widely available in classrooms, and their presence brings new concerns along with opportunities. The arrival of computers in the classroom is so new that there has not yet been a definitive evaluation of their impact on the learning process, either in general or within the advanced physics community

Revolution in Scientific Publishing

A revolution in scientific publishing is under way. Physics journals in particular are rapidly migrating toward electronic formats. Already some major U.S. laboratories have begun to phase out their actual libraries in favor of electronic access. Similar experiments have begun at the physics libraries of some of the nation's research universities. The whole physics publishing enterprise has been radically changed by the creation of electronic archives such as the Los Alamos http://www.lanl.gov. A decade ago only the single field of theoretical particle physics used this model. Today most fields of physics, mathematics, and other scientific disciplines are using it, and it has spread to the medical community through the recent creation of a server sponsored by the National Institutes of Health. It is clear that working research scientists already have a new manner of carrying out research. Both national and international collaborative scientific research efforts are supported through cyberspace. New research is created, posted on servers, and downloaded by other scientists, who then synthesize it and create their own new results at a more rapid pace than ever before.

Cyberspace Technology in College and High School Classrooms

In colleges and universities, experimentation with cyberspace technology and "new-technology classrooms" is beginning. Computers have already made their way into the traditional college physics laboratory, most significantly in the acquisition and analysis of data. In addition, many college instructors make themselves available to their students via e-mail, enabling questions and discussions to be undertaken at the convenience of both student and instructor. Literature searches are now often done electronically.

These developments have implications for the education of secondary school students currently engaged in the advanced study of physics. Various computer software programs are available for the tasks of communication (electronic mail, browsing on the Web, presentational tools, text editing, slide presentation [e.g., Power Point], and IR [infrared] personal response) and computer-assisted conceptualization (modeling environments, spreadsheets, symbolic manipulation, mathematical graphing, computer-aided design, simulation and visualization, and data collection and analysis). All of these tools are used for a wide variety of research carried out by physicists. The panel recommends that these modern research tools be introduced as extensively as possible into advanced high school physics programs. The panel notes that many high schools are already using a number of these tools, especially software for data acquisition and analysis.

Communication Among Constituencies with an Interest in Physics Research or Education

The rapid speed of communication via CIT presents new opportunities for a closer relationship between the physics research and teaching communities. Many researchers at universities, government laboratories, and other organizations have created Web sites that are freely accessible and designed precisely for the purpose of making their research more available to the general public. The same can be said for the American Physical Society and other professional organizations of physicists.

It is therefore possible, as never before, to introduce topics of ongoing research to secondary school students currently studying advanced physics. Using CIT, researchers can best communicate the excitement of their research activity as they grapple with the scientific problems that lie at the boundaries of knowledge in the field. This excitement, when transmitted properly to students, can be a tremendous motivating factor leading them to consider scientific research as a career.

In addition, the Web allows easy access to university physics courses from outside university classrooms. Many professors offer Web-based mechanisms for their own students to monitor their courses. Often, course syllabi, homework assignments and solutions, and the like are made available via an appropriate Web site. Such mechanisms also offer exciting new possibilities for more closely linking physics instruction within the universities to that in secondary education programs. The panel recommends that CIT be used in the teaching of advanced high school physics to highlight current state-of-the-art research, thereby encouraging young people to join the nation's scientific workforce.

Future Uses of CIT in Advanced Physics Programs

There are a number of ways in which CIT poses challenges to be met in future advanced physics instruction. In this section, we outline the research needed to answer the question: "What might be the form of an advanced physics course in the year 2010?"

Because the possibilities are so vast, any categorization of the issues involved in answering this question is to some extent arbitrary. Nevertheless, we provide the following list of issues to provide a framework within which to conceptualize and begin to formulate specific goals and recommendations for the electronic advanced physics classroom of the not-too-distant future. The list is not meant to be exhaustive and is sure to grow as the nation's educational leadership becomes increasingly aware of the enormous opportunities presented by CIT:

- What is the appropriate use of CIT in teaching advanced physics courses?
- In the teaching of advanced physics courses, how is it possible to foster a higher level of skill in the use of modern CIT to acquire, analyze, disseminate, and present data and information?
- Is it possible to use CIT to close the gap between calculus-based and algebra-based physics courses by developing new computer-based modes of thinking about and handling conceptual and quantitative models of physical reality?
- What is the best way to foster the development of high-quality CIT-based materials (e.g., hypertext) that will support the teaching of advanced physics courses?
- What is the appropriate level of teacher training necessary for the effective use of CIT in an advanced physics course?
- What are the appropriate standards of student attainment and proficiency in the use of CIT that should be required of a student enrolled in a high-quality advanced physics course?
- What is the appropriate use of the Web as a medium for delivering distance learning in an effort to provide advanced physics instruction to the broadest possible population of students that can benefit from such training?

Potential Use of CIT to Administer Final Examinations in Future Advanced Physics Programs

In the not-too-distant future, CIT may be able to provide an efficient means of administering and scoring final examinations in advanced programs. If such a process is implemented, the panel makes two recommendations:

- It is absolutely essential that students retain the ability to return to and modify their answers to previous questions as they take the examination. Physics is a subject in which careful consideration and reconsideration are often required to find a correct solution to a problem. A fair physics test must reflect that essential feature of the discipline.

- The implications of adaptive questioning (in which succeeding questions depend on the responses given by the student to earlier questions) need to be carefully studied. The panel is skeptical that adaptive schemes can be devised that are truly fair to all candidates.

INTERDISCIPLINARY CONNECTIONS

An important issue for a field as ancient as physics is how it adapts to the needs of society in a given place and time. The field of physics today faces a period of transition. Among the most important reasons for this are the following:

- The period in which a primary national need for defense was fulfilled by physicists in creating, developing, and upgrading nuclear weapons has ended.
- A period in which technology is a primary driver of the national economy has begun.
- A period in which other areas of science, such as microbiology and genetics, will undergo rapid progress has also begun.
- The increasing availability, power, and sophistication of computational hardware and software will make possible novel quantitative descriptions of the physical universe. Society in general appears to be rapidly becoming more and more knowledge based. Enormous quantities of information are instantly available on ubiquitous computers. (See the discussion in the preceding section.)

Under these circumstances, the tasks that are undertaken by the field of physics must change both to meet the demands of society and to maintain the vitality of the field itself. Physicists, and the people trained by them, will need to be able to apply the body of knowledge developed within physics to totally new areas. In other words, physicists will be asked to become more interdisciplinary; they will have to apply their special knowledge and methods to problems that cross the boundaries of traditional disciplines. This fact has substantial implications for the training of the future physicists presently engaged in the advanced study of physics at the secondary level. It therefore makes sense to examine the two dominant advanced physics programs to determine the extent to which they provide suitable training to students along interdisciplinary lines.

The AP physics program appears to stick closely to the traditional curriculum that has been the hallmark of the field during the last 50 years. There appears to be no attempt within the program to address the increasing importance of applying physics knowledge across traditional field boundaries.

On the other hand, the IB program has several features that naturally allow students to begin to confront interdisciplinary issues. First, the IB program provides interdisciplinary options (biomedical physics, historical physics) that teachers may choose. Second, many questions from past IB examinations have an interdisciplinary flavor. Finally, during the Group 4 project component of the IB program, a collaborative group of students creates its own scientific investigation. Such projects can easily involve applying knowledge and methods from several different scientific fields.

Increased interdisciplinary content could be added to advanced courses by developing more separate units such as the biomedical physics unit found in the current IB program. Alternatively, the advanced course might choose examples illustrating how fundamental physical principles apply to a wide variety of areas. For example, the elastic properties of DNA molecules might be used to discuss the range of validity of Hooke's law for spring forces. Biological cell membranes could be used to construct interesting examples of electrical potential differences and electric fields.

The panel, in agreement with the National Research Council's (NRC) *National Science Education Standards* (*NSES*) (NRC, 1996), recommends that all advanced high school physics curricula include some experience with interdisciplinary applications of physics.

COMPARISON OF AP AND IB PHYSICS WITH EDUCATION STANDARDS

Extent to Which the AP and IB Physics Programs Reflect the Recommendations of the *National Science Education Standards*

The panel did not have sufficient time to make a detailed assessment of the extent to which the AP and IB Physics programs incorporate the recommendations of the *NSES* (NRC, 1996). The short answer to the question is "not much." As noted earlier, IB physics encourages interdisciplinary connections to some extent as recommended by the *NSES*.

Since most advanced courses in physics are designed to mimic college-level courses, and since the college-level courses are not (for better or worse) specifically designed with the *NSES* in mind, there is no immediate need for the advanced courses to be tightly tied to the standards. However, as more and more high schools adopt curricula in line with the *NSES*, college courses may evolve to take into account the new background that students then bring with them. We would then expect high school advanced courses to be redesigned as well.

Extent to Which the AP and IB Physics Programs Reflect the Recommendations in the National Council of Teachers of Mathematics Standards 2000

The National Council of Teachers of Mathematics recently published *Principles and Standards for School Mathematics* (NCTM, 2000). This document presents five principles and a series of standards to guide the teaching and learning of K–12 mathematics. The standards are grouped into several categories: Numbers and Operations, Algebra, Geometry, Measurement, Data Analysis and Probability, Problem Solving, Communication, Connections and Representations. Throughout the Principles and Standards is an emphasis on understanding, "Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge." Indeed, "learning with understanding" may well be the clarion call of the entire document. The standards are intended as goals to be met by all K–12 students.[30]

These standards do not directly address the issue of advanced physics study in high school. They do, however, provide a strong foundation on which advanced courses can be built. Certainly, it is desirable that any student undertaking the study of advanced physics in high school have met the NCTM standards before beginning that course. It should also be noted that high school physics courses in general, and advanced physics courses in particular, help students solidify their knowledge and skills in mathematics. Advanced physics courses are of special value in reinforcing skills in Measurement, Data Analysis and Probability, Problem Solving, Communication, and Connections and Representations.

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[30] More information on the standards can be found at the NCTM Web site: http://nctm.org/standards/introducing.htm [4/23/02].

6

Connecting Advanced High School Physics Programs with College Physics Programs

One of the principal rationales for advanced study in secondary schools is to enable capable and motivated students to do work that is beyond the normal secondary school level. Advanced study both removes an artificial cap on these students' learning in high school and facilitates their future learning in colleges and universities. Clearly, our success in nurturing our most talented students depends on just how well we accomplish this task.

QUALITY OF PREPARATION OF AP AND IB PHYSICS STUDENTS FOR FURTHER STUDY

The College Board presents evidence that students who do well on the Advanced Placement (AP) physics examinations perform in physics courses beyond the introductory level as well as, or perhaps even a bit better than, students who first encounter introductory physics in the standard college or university course (see, for example, College Entrance Examination Board, 1994c). About 10 years ago, one panel member administered the AP Physics B exam to students in that member's introductory college physics course. There was a good correlation between the students' performance on the AP exam and their grades in the college course.

Both these pieces of evidence can be interpreted as showing that scores on the AP physics exams are good predictors of success in college physics courses beyond the introductory level. Of course, one might legitimately question whether that is the primary raison d'être of advanced high school courses. One could argue, however, that for those students for whom college placement or credit is a goal the AP courses are reasonable substitutes for most introductory college-level courses.

The International Baccalaureate (IB) physics curriculum is not designed to be a substitute for college-level work. However, the panel believes the IB physics curriculum provides fine preparation for introductory college-level work in physics. In terms of content, the IB physics curriculum is roughly equivalent to that of AP Physics B.

The demonstrated success of many highly qualified AP students in college courses beyond the introductory level confirms that these students can be as well prepared as those taking the introductory college course. However, there is evidence to suggest that the College Board's estimation that a score of 3 on an AP examination indicates a student is qualified for advanced placement may be too generous, and in practice most selective colleges require a score of 4 or 5 for placement or credit (Lichten, 2000). This latter practice is consistent with the panel's recommendation that a higher standard for qualification on a more conceptually oriented, less rushed examination would be an improvement (see Chapter 2). From this point of view, the successful skipping of introductory college courses by AP students might be construed as an indictment of introductory college physics courses rather than as an endorsement of AP courses.

DEPENDENCE OF COLLEGE PHYSICS PROGRAMS ON KNOWLEDGE GAINED FROM ADVANCED HIGH SCHOOL PHYSICS PROGRAMS

From the point of view of many college physics departments, there are serious problems with the interface between advanced high school programs and college physics programs. The content of AP courses is designed as an aggregate of the content of many large introductory science courses at major universities. Since these university courses vary widely, "averaging" their content into a single high school course produces a topic outline with greater diversity than any single university course. This holds especially true for the AP Physics B courses. As a result, the AP courses generally cover a content range that is very broad but not very deep. The courses tend to encourage memorization and technical problem solving without deep conceptual understanding, though that is of course not their intent. It is well established that learning of this kind is not easily generalized to new situations. Thus, the potential of physics education to contribute to the development of capable problem solvers is not fully realized.

In addition, there are many obstacles to creating a college-level instructional environment in secondary schools. For example, the rapid expansion of the AP program has caused a severe shortage of adequately trained teachers capable of teaching AP courses well (see Chapter 4). For these and other reasons, many of those responsible for granting advanced placement or credit in the colleges and universities doubt at present that students scoring 3 or 4, or in some cases even 5, on AP physics examinations actually have had experiences warranting the granting of such placement or credit, and some decline to do so. In addition, as noted earlier, many students who have taken AP courses do not even take the AP examinations. The net result of this situation is that many students who have supposedly done college-level work in secondary school are destined to repeat that work once they enter college. Some even decide not to continue in physics rather than follow that path. While some of these students benefit from the college physics courses taken after an AP experience, the lack of coordination between secondary and higher physics education is problematic.

IMPROVEMENTS IN COLLEGE PHYSICS INSTRUCTION THROUGH A BETTER INTERFACE WITH ADVANCED HIGH SCHOOL PROGRAMS

College courses are subject to the same criticism of excessive breadth that has been made of advanced high school programs, as has been emphasized many times in the physics education research literature.[31] These courses often fail both in improving students' conceptual understanding and in motivating them to continue. If high school programs of advanced study were to focus on a somewhat narrower but widely shared range of content, and if the learning process were to emphasize conceptual understanding, college and university physics courses could evolve to build on that content and understanding. For example, suppose that a deeper and more reliable knowledge of Newtonian mechanics could be achieved through advanced study in high school, as recommended in Chapter 2, with performance on examinations correlating well with established measures of conceptual understanding. Then college courses for graduates of advanced physics programs could reduce the time spent on mechanics and devote some of the time saved to topics that are conceptually difficult, such as electromagnetic fields. The net result would be enhanced student understanding at both levels.

It might also be possible, with some of the time saved, to include more contemporary physics.[32] It is unfortunate that many of our most talented and advanced physics students spend 3 years surveying essentially the same material of classical physics (2 secondary years and 1 college year). As discussed earlier, their motivation and knowledge would be enhanced by some exposure to physics as it has evolved in the last few decades. This cannot be done properly in the time available unless some greater success in coordinating secondary and higher-level physics courses can be achieved.

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[31] See Chapter 3 and the discussion of the Introductory University Physics Program evaluations in Coleman, Holcomb, and Rigden (1998).

[32] The new IB physics syllabus includes particle production and annihilation; fundamental interactions; and an overview of leptons, quarks, and exchange bosons. The panel applauds the addition of these contemporary physics topics to the IB program.

Of course, not all students entering college will have studied advanced physics in high school, and that fact must also be taken into account when designing college course offerings. How to derive the optimum benefit from the physics background of incoming students is an issue that colleges will need to study carefully in the future.

RECOMMENDATIONS

The panel makes the following recommendations for creating a reliable interface between advanced high school and college physics programs:

- As discussed in Chapter 2, all advanced high school programs should seek to develop competence in Newtonian mechanics that emphasizes deep conceptual understanding, even if the coverage of other topics must be reduced.
- Final assessments must be modified to test for conceptual understanding and the ability to apply basic physical principles to situations not previously encountered.
- Colleges and universities and writers of textbooks should develop introductory courses and materials that take advantage of this enhanced understanding of Newtonian mechanics among the rapidly growing population of advanced high school program graduates. The amount of duplication between the high school and college courses could then be reduced, making possible a decrease in the excessive breadth of many of the college courses as well.

7

Main Findings and Overall Recommendations

This chapter summarizes the panel's main findings and overall recommendations. References to earlier chapters are provided to help the reader find more comprehensive discussion of these important issues.

1. The most important goals of advanced physics instruction are independent of the particular topics studied.

Advanced physics instruction should be aimed at generating excitement and enthusiasm for further study in physics, at achieving deep conceptual understanding of the subject matter covered, and at instilling in students the scientific habits of mind that are important for their further education in science. Learning any particular physics subject matter is of lesser importance (see Chapter 2).

2. All advanced physics programs should aim to develop deep conceptual understanding of the topics studied.

To achieve the above goals, it is essential that whatever topics are chosen be addressed in depth, with an emphasis on conceptual understanding rather than on technical problem-solving skills. Students must learn that physics knowledge is built on general principles and gain the confidence to apply those principles to unfamiliar situations (see Chapters 2 and 3).

It is critical that advanced physics programs allow enough time for extended debate, student-designed experimentation, and other activities necessary to develop depth of understanding. There must also be sufficient time for teachers to diagnose the current state of understanding of their students and to change their teaching techniques and objectives accordingly. Of course, it is impossible to assess the understanding of students without requiring them to explain their reasoning. The panel strongly recommends that explanations of reasoning be required from the first day of an advanced course, so that providing such explanations quickly becomes automatic for all students in whatever they do in the course (see Chapter 4). For these reasons, very broad curricula, such as 1-year Advanced Placement (AP) Physics B courses, should either be extended to 2 years (as is done in International Baccalaureate physics) or eliminated in favor of more compact curricula that can be covered in depth (see Chapters 2 and 3).

3. All students of advanced physics should study a nationally standardized one-semester unit in Newtonian mechanics. This unit should have the coverage of current AP Physics C Mechanics (including rotational dynamics) but should not require formal calculus.

The study of Newtonian mechanics provides an ideal framework for developing the scientific habits of mind and deep conceptual understanding that are the primary goals of advanced physics instruction. Since familiarity with Newtonian mechanics is universally expected of students who have completed an advanced high school physics program, it is logical to create a standardized mechanics unit to serve as the foundation of all advanced physics study. College physics departments could then depend on a thorough knowledge of this unit in developing courses for the further education of advanced physics students (see Chapters 2 and 6). This new common unit should contain all the important physics currently found in the AP Physics C Mechanics curriculum, including rotational dynamics. To permit the study of the common mechanics unit by all advanced physics students, however, knowledge of formal calculus should not be required (see Chapter 2).

It is important to understand that the omission of formal calculus would have no adverse impact on achieving the important goals of advanced physics instruction. On the contrary, it would permit increased emphasis on conceptual understanding by eliminating the need to spend time studying calculus-intensive problems. For example, students would no longer need to be able to perform path integrals to find the work done by a force, but they would need to understand the connection between work and kinetic energy change. They would also have to be able to find the work done by a force that varies as a function of position by using the area under the force curve.

We note that this recommendation is in keeping with the recent trend on AP Physics C examinations to reduce the emphasis on mathematical complexity. When the concepts of calculus are essential to the development of the physics, these concepts can be introduced in other ways. For example, instantaneous velocity can be introduced as the slope of a tangent line to the graph of displacement versus time.

Finally, the panel stresses that the examination for the common mechanics unit is likely to be more difficult than the present AP Physics C Mechanics examination. For one thing, research has shown that students have more difficulty with the kinds of conceptual questions that would make up the new examination than with problems that can be solved by mathematical techniques. In addition, successful students will be expected to be thoroughly familiar with the new mechanics unit, and the standards for success on the examination will be higher than they are now. The consolidation of mechanics into a single common unit does not by any means represent a lowering of present standards, but quite the opposite (see Chapter 2).

4. In a 1-year advanced physics program, students should study only one major area of physics in addition to Newtonian mechanics.

To keep the size of the curriculum manageable, the panel strongly recommends that 1-year programs cover only one other major area of physics beyond Newtonian mechanics. There should be great flexibility in the choice of the optional topic to be covered in the second semester, including the possible choice of a nontraditional unit designed to provide advancement by enrichment. (See Chapter 2.)

5. Meaningful real-world (laboratory) experiences should be included in all advanced physics programs. There is ample evidence that traditional "cookbook" laboratories do not meet this standard.

The panel strongly believes that real-world experiences are an essential part of advanced physics study. Science is distinguished from other ways of thinking by its reliance on evidence about the physical world and the importance of reproducible consistency in judging the truth of conjectures, laws, and theories. However, these experiences must be meaningful; that is, the educational benefits derived from the activities must be worth the time and effort expended. There is ample evidence that traditional cookbook laboratories do not meet this standard (see Chapter 2).

6. Teachers of advanced programs must be able to respond to their ongoing assessment of their students' understanding (see Chapter 4).

Therefore, curricula that require spending specific amounts of time on particular subject areas or on certain kinds of activities should be avoided.

7. The scoring of written examinations must emphasize the evaluation of student understanding. A rigid scoring rubric in which points are awarded for very specific correct responses to small parts of each question is not appropriate; rather, the reader should evaluate the student's response as a whole. A maximum score should be given only for complete and clear physical reasoning leading to the correct

conclusions. The recent trend toward increased emphasis on conceptual understanding should continue.

Because the final assessments in advanced programs involve high stakes, students and teachers tend to do whatever they must in order to score well on those assessments. This fact makes it absolutely imperative that the examinations measure the depth of understanding that is the fundamental goal of advanced physics instruction (see Chapter 2).

The assessment of understanding necessitates requiring students to explain their reasoning and evaluating those explanations. Since there is no way to anticipate all possible correct and incorrect explanations, it is impossible to perform this evaluation within the confines of a rigid scoring rubric. Current rigid rubrics must therefore be abandoned in favor of a more flexible approach in which each student's response is evaluated as a whole. This is the approach taken in grading essay questions in the humanities or social sciences, without any apparent problems due to lack of consistency in evaluation. Moreover, one member of the panel participated in an experiment in which AP physics examinations were graded in this fashion, and the consistency of the evaluation turned out to be at least as good as under the rigid scoring rubric (see Chapter 2).

8. The panel recommends that sufficient time be allowed for students to complete the entire final examination (see Chapter 2). Final examinations must measure what students know, not how fast they can recall and apply that knowledge.

9. The standards for success on final assessments should be raised.

The panel believes that if its recommended curriculum changes are implemented, successful students will know the material in the new, more manageable curricula thoroughly. Therefore, the panel recommends high standards of performance on the new final examinations (see Chapter 2).

10. More well-qualified teachers are desperately needed for advanced physics programs. A concerted effort should be made throughout the physics community to contribute to the training of highly skilled physics teachers. Peer assessment programs should be implemented for certification and continuing assessment of physics teaching skill.

With the continued growth of advanced physics programs across the nation, there is a severe shortage of qualified teachers for such programs. The panel endorses a concerted effort by all elements of the physics community to train more qualified teachers. It is also imperative that the salaries and professional status of physics teachers be raised to make them competitive with those of other professionals, so that sufficient talent will be attracted to the physics teaching profession (see Chapter 4).

The panel also recommends that, as is done in other professions (e.g., medicine), peer assessment programs be implemented for the certification of physics teachers and the continuing evaluation of their teaching skills. On this matter, we endorse the National Board for Professional Teaching Standards; however, we recommend that peer assessment be discipline specific rather than for all sciences.

11. The preparation and skill of the teacher are the principal factors that determine the ultimate success or failure of advanced physics instruction. Thorough understanding of the subject matter is a necessary but not sufficient condition for good physics teaching. Teachers must also be trained in the special pedagogy of physics.

The panel stresses that implementations of advanced physics programs differ widely from school to school. The way in which a program is implemented by a given teacher is often much more important than the choice of which program to implement (see Chapter 4).

12. Skilled physics teachers continually diagnose the understanding of their students and change their objectives and strategies as that diagnosis indicates. It is impossible to assess the understanding of students without requiring them to explain their reasoning. (See Chapter 4.)

13. Advanced courses should have greater interdisciplinary content and make increasing use of cyberspace and information technology.

Modern developments in both science and society as a whole indicate that physicists will be increasingly called upon to address problems that cross the boundaries between traditional disciplines (see Chapter 5). At the same time, the explosion of information technology provides a vast array of possibilities for improving advanced physics instruction (see Chapter 5). Teachers and administrators should be aware of these developments and help advanced physics programs expand their involvement in both areas over time.

14. Information technology should be used to create networks that will enable teachers, college faculty, and other professionals to share information useful for advanced physics teaching.

The Internet provides a rapid mechanism for exchanging ideas and information among professionals interested in advanced physics instruction. The panel encourages the continued expansion of networks of such professionals. Such networks are a powerful means of encouraging the creation of a professional community of physics teachers, consistent with the panel's recommendations for peer assessment (see recommendation 10) and greater emphasis on professional development (see Chapters 4 and 5).

15. Fairness must be ensured on future computerized final assessments for advanced physics programs.

The panel is aware that the use of information technology may allow more efficient administration of nationwide examinations for advanced physics programs. However, the panel stresses the importance of ensuring that these more efficient assessments remain fair to all candidates.

16. Given the scarcity of data on the long-term outcomes of physics education, an effort should be made as soon as possible to follow the progress of physics students over many years.

The panel believes there are far too few data on the long-term outcomes of physics education to allow important decisions about the physics education of large numbers of students to be made with confidence.

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Appendix A

Charge to the Content Panels from the Parent Committee

Charge to the Parent Committee and Content Panels: The charge to the committee is to consider the effectiveness of, and potential improvements to, programs for advanced study of mathematics and science in American high schools. In response to the charge, the committee will consider the two most widely recognized programs for advanced study: the Advanced Placement (AP) and the International Baccalaureate (IB) programs. In addition, the committee will identify and examine other appropriate curricular and instructional alternatives to IB and AP. Emphasis will be placed on the mathematics, physics, chemistry, and biology programs of study.

Charge to Content Panels: The content panels are asked to evaluate the AP and IB curricular, instructional, and assessment materials for their specific disciplines.

Below is a list of questions that the content panels will use to examine the curriculum, laboratory experiences, and student assessments for their specific subject areas. The content panels will use these questions to issue a report to the committee about the effectiveness of the AP and IB programs for educating able high school students in their respective disciplines. In answering these questions, the content panels should keep in mind the committee's charge and study questions.

The panels should focus on the following specific issues in advising the committee:

I. CURRICULAR AND CONCEPTUAL FRAMEWORKS FOR LEARNING

Research on cognition suggests that learning and understanding are facilitated when students: (1) have a strong foundation of background knowledge, (2) are taught and understand facts and ideas in the context of a conceptual framework, and (3) learn how to organize information to facilitate retrieval and application in new contexts (see, e.g., National Research Council [NRC], 2000).

1. To what degree do the AP and IB programs incorporate current knowledge about cognition and learning in mathematics and science in their curricula, instructions, and assessments?
2. To what degree is the factual base of information that is provided by the AP and IB curricula and related laboratory experiences adequate for advanced high school study in your discipline?
3. Based on your evaluation of the materials that you received, to what extent do the AP and IB curricula and assessments balance breadth of coverage with in-depth study of important topics in the subject area? In your opinion, is this balance an appropriate one for advanced high school learners?
4. Are there key concepts (big ideas) of your discipline around which factual information and ideas should be organized to promote conceptual understanding in advanced study courses (e.g., Newton's laws in physics)? To what degree are the AP and IB curricula and related laboratory experiences organized around these identified key concepts?
5. To what degree do the AP and IB curricula and related laboratory experiences provide opportunities for students to apply their knowledge to a range of problems and in a variety of contexts?
6. To what extent do the AP and IB curricula and related laboratory experiences encourage students and teachers to make connections among the various disciplines in science and mathematics?

II. THE ROLE OF ASSESSMENT

Research and experience indicate that assessments of student learning play a key role in determining what and how teachers teach and what and how students learn.

1. Based on your evaluation of the IB and AP final assessments and accompanying scoring guides and rubrics, evaluate to what degree these assessments measure or emphasize:
    a) students' mastery of content knowledge;
    b) students' understanding and application of concepts; and
    c) students' ability to apply what they have learned to other courses and in other situations.
2. To what degree do the AP and IB final assessments assess student mastery of your disciplinary subject at a level that is consistent with expectations for similar courses that are taught at the college level?

III. TEACHING

Research and experience indicate that learning is facilitated when teachers use a variety of techniques that are purposefully selected to achieve particular learning goals.

1. How effectively do the AP and IB curricula and assessments encourage teachers to use a variety of teaching techniques (e.g., lecture, discussion, laboratory experience and independent investigation)?
2. What preparation is needed to effectively teach advanced mathematics and science courses such as AP and IB?

IV. EMPHASES

The NRC's *National Science Education Standards* and the National Council of Teachers of Mathematics' Standards 2000 propose that the emphases of science and mathematics education should change in particular ways (see supplemental materials).

1. To what degree do the AP and IB programs reflect the recommendations in these documents?

V. PREPARATION FOR FURTHER STUDY

Advanced study at the high school level is often viewed as preparation for continued study at the college level or as a substitute for introductory-level college courses.

1. To what extent do the AP and IB curricula, assessments, and related laboratory experiences in your discipline serve as adequate and appropriate bases for success in college courses beyond the introductory level?
2. To what degree do the AP and IB programs in your discipline reflect changes in knowledge or approaches that are emerging (or have recently occurred) in your discipline?
3. How might coordination between secondary schools and institutions of higher education be enhanced to optimize student learning and continued interest in the discipline?

Appendix B

Biographical Sketches of Physics Content Panel Members

S. James Gates, Jr., the John S. Toll Professor of Physics, is the director of the Center for String and Particle Theory at the University of Maryland at College Park. His research focus is in mathematical and theoretical physics. Dr. Gates served on the National Research Council (NRC) Joint Strike Technical Review Panel and the Task Group I-Combat Power committee. He has taught university-level mathematics and physics for 30 years and has lectured on general education issues, consulted with the Educational Testing Service, worked on a municipal high school curriculum, and chaired the Howard University physics department. The Washington Academy of Science recognized him as its 1999 College Science Teacher of the Year. Dr. Gates received two B.S. degrees and a Ph.D. from the Massachusetts Institute of Technology.

David Hammer is an associate professor with joint appointments in Physics and Curriculum & Instruction at the University of Maryland, College Park. He conducts research in physics education, focusing on students' beliefs about knowledge and learning as well as on teachers' interpretations of the strengths and weaknesses in student thinking. Dr. Hammer earned his Ph.D. in Science and Mathematics Education and his MA in Physics from the University of California at Berkeley.

Robert C. Hilborn is the Amanda and Lisa Cross Professor of Physics at Amherst College, where he teaches introductory and advanced-level physics. Dr. Hilborn's current research focuses on testing the symmetrization postulate for identical particle systems in quantum mechanics, a study of the effects of dynamic Stark shifts on laser-excited atoms, and control schemes for chaotic systems. Dr. Hilborn is involved in physics education and has served as president of the American Association of Physics Teachers. In this position, he interacted with high school physics teachers and also has worked with high school teachers while at Amherst. He is chair of the newly established National Task Force on Undergraduate Physics. Dr. Hilborn earned his Ph.D. from Harvard University.

Eric Mazur is at Harvard University where he is a Harvard College professor, Gordon McKay Professor of Applied Physics, and professor of physics. Dr. Mazur's research in optical physics includes contributions in light scattering, spectroscopy, and electronic and structural events in solids. Dr. Mazur also conducts research in improving science education, becoming well known for his "peer instruction" method for teaching large lecture classes. Dr. Mazur will complete his term on the Advanced Placement test development committee this spring. At the NRC, Dr. Mazur has served on the Working Group on Science Assessment Standards. Mazur received his Ph.D. in experimental physics from the University of Leiden in the Netherlands.

Penny Moore taught physics 60-percent time at Piedmont High School in Piedmont, California for twenty-five years and worked concurrently at the University of California, Berkeley. During this time she designed, obtained funding for, and directed three large national science education programs: The Science for Science Teachers and PRIME Science programs, both funded initially by the National Science Foundation, and The Journey Inside with Intel Corporation. In August 2000, she left a fulltime position in the physics department at Berkeley to work as director of Science and Math Education in the College of Mathematical and Physical Sciences at The Ohio State University in Columbus. At the NRC, Ms..Moore served on the Working Group on Science Assessment Standards and was a leader in assembling *Science Teaching Reconsidered.*

Robert A. Morse is a physics teacher at St. Albans School in Washington, DC, where he has taught physics and AP physics for 20 years. Dr. Morse has been recognized for his teaching with the Presidential Award for Excellence in Science Teaching, the Tandy Technology Scholar Award, the American Association for Physics Teachers (AAPT) Award for Excellence in Pre-College Teaching, and was named the American Physical Society Distinguished Physics Teacher for the District of Columbia for the APS Centennial. Dr. Morse has been active in the AAPT, where he has developed and presented workshops on teaching physics. At the NRC, he served as a panelist for the How People Learn Conference. He received his Ph.D. in Science Education from the University of Maryland at College Park, his M.Ed. from Boston University, and a BA in Physics from Cornell University.

Robin Spital (committee liaison and chair) is a teacher of Honors and Advanced Placement Physics at The Bolles School in Jacksonville, Florida. His career began at Illinois State University in Normal, where he was assistant professor of physics. He subsequently worked in the private sector as principal development engineer for the AAI Corporation in Hunt Valley, Maryland, and as principal scientist for Pfizer Medical Systems. Dr. Spital received his Ph.D. in theoretical high-energy physics from Cornell University.