Project Physics. A Report on Its Aims and Current Status

Gerald Holton

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Project Physics. A Report on Its Aims and Current Status

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Introduction

During the last few years, about eighty physicists, teachers, film makers, experts on testing and others have been collaborating at Harvard Project Physics to produce a one year course in physics for use in high schools and in junior colleges. In 1962 I began a feasibility study with F. James Rutherford and Fletcher G. Watson, using a grant from the Carnegie Corporation. In October 1963 the National Science Foundation called a meeting in order to stimulate the formation of a larger national curriculum project for which a need had become increasingly evident. As a result, we agreed to start work in June 1964 on a larger scale. Funds have been granted by the Carnegie Corporation, Alfred P. Sloan Foundation, the U.S. Office of Education, and the National Science Foundation.

A pilot version of the course now exists, and the materials we have written, designed, and manufactured (see Fig. 1) are now being tried out with over 2600 students on a controlled experimental basis in more than fifty schools throughout the United States (see Fig. 2 and Table I). After further revisions, we plan a thorough trial next year involving about one hundred schools that have agreed to try Project Physics—nearly half of which were chosen at random. By late next year or early in 1969 we hope to have available not only most of the tested course materials, but also a thorough evaluation report, based on the experience of the final test year.

From the beginning we planned on writing, testing and rewriting the materials every year during the four-year cycle, so we have been able to change our minds on quite fundamental things in the light of feedback from our classes. And this process will continue for a year or so. This freedom to work carefully and under classic conditions of experimentation, so familiar in physics research itself, has been precious to all of us. Because in a laboratory situation one waits for results before one goes public, and because we have only about half the funds we could wisely be using in this work, we have been trying to keep as quiet as this world allows. We have concentrated on giving detailed and frequent briefings for those who actually work with the Project, or those such as the AAPT–AIP Regional Counselors who have expressed an interest in early collaboration.

Now the time has come to give a progress report to our colleagues; herein we shall share with you some of our ideas and questions. We shall tell you of the vision we have for this course development, and indeed for curriculum development in general. We shall relate some of the difficulties we still have to conquer. In short, we want to inform you of our work so far, and to invite your collaboration in bringing this Project to a successful conclusion and into widest classroom use.

Participants in Harvard Project Physics

In terms of actual participants so far, either full-time while on leave at the Project headquarters at Harvard University or as consultants, the list of those who have helped already is long and distinguished; so is the Advisory Committee of the Project to whom we are responsible (see Tables II and III). The distribution of fields represented in both lists is symbolic of our decision to draw from a great variety of fields and competences: in addition to physicists and high school teachers, one finds chemists, historians of science, philosophers of science, science educators, and experts interested in publishing and in scientific manpower problems. In all our planning and work, from the outset, we have intentionally built on the broadest possible base.

Here again the unique arrangement of having three codirectors is significant: Professor Watson of the

Fig. 1. Some of the materials developed by and/or furnished to trial schools by Project Physics 1966-7.

This article is based on an invited paper given at the APS–AAPT Meeting in New York, 1 February 1967.

Harvard Graduate School of Education is a science educator who has also done professional work as an astronomer; Dr. Rutherford of the faculty of the Harvard Graduate School of Education is a former high school teacher and our superb administrator, ever senstive to the day-to-day needs and possibilities of the classroom; and I am a physicist who is also working in the history of science. This triumvirate arrangement has allowed us to keep in working contact with a whole range of professions from the very beginning.

Table I. Participating Schools or School Districts 1966-67

West High School
Phoenix, Arizona

Berkeley High School
Berkeley, California

Claremont High School
Claremont, California

Laguna Beach High School
Laguna Beach, California

Los Altos High School
Los Altos, California

The Thatcher School
Ojai, California

Henry M. Gunn Senior High School
Palo Alto, California

Capuchino High School
San Bruno, California

San Diego High School
San Diego, California

Clairemont High School
San Diego, California

Santa Fe High School
Santa Fe Springs, California

Lowell High School
Whittier, California

Wheat Ridge High School
Wheat Ridge, Colorado

Staples High School
Westport, Connecticut

The Loomis School
Windsor, Connecticut

Nova High School
Fort Lauderdale, Florida

Melbourne High School
Melbourne, Florida

Fulton High School
Atlanta, Georgia

Senn High School
Chicago, Illinois

Osage Community Schools
Osage, Iowa

Catholic High School of Baltimore
Baltimore, Maryland

Lansdowne Senior High School
Baltimore, Maryland

Burlington High School
Burlington, Massachusetts

Canton High School
Canton, Massachusetts

Dorchester High School
Dorchester, Massachusetts

Simon's Rock
Great Barrington, Massachusetts

Newton South High School
Newton Centre, Massachusetts

Henry Ford High School
Detroit, Michigan

Interlochen Arts Academy
Interlochen, Michigan

J. W. Sexton High School
Lansing, Michigan

Convent of the Visitation
Saint Paul, Minnesota

Omaha Benson High School
Omaha, Nebraska

Valley High School
Las Vegas, Nevada

Phillips Exeter Academy
Exeter, New Hampshire

Brooklyn Technical High School
Brooklyn, New York

Burnt-Hills-Ballston Lake Central Schools
Burnt Hills, New York

Mater Christi Diocesan High School
Long Island City, New York

Paul D. Schreiber High School
Port Washington, New York

Princeton High School
Cincinnati, Ohio

Talawanda High School
Oxford, Ohio

Solon High School
Solon, Ohio

Grant High School
Portland, Oregon

South Philadelphia High School
Philadelphia, Pennsylvania

Plymouth-Whitemarsh Joint School System
Plymouth Meeting, Pennsylvania

Oak Ridge High School
Oak Ridge, Tennessee

St. Mark's School of Texas
Dallas, Texas

Logan High School
Logan, Utah

Kennewick Senior High School
Kennewick, Washington

Mercer Island Senior High School
Mercer Island, Washington

Rice Lake High School
Wisconsin

West Vancouver Secondary School
West Vancouver, B.C., Canada

John Rennie High School
Pointe Claire, P.Q., Canada

Menntaskolinn Ad
Laugarvatni, Iceland

Fig. 2. Locations of fifty-three trial schools 1966–7.

Table II. Advisory Committee of Project Physics

E. G. Begle, Director, School Mathematics Study Group
Stanford University

Paul Brandwein, Director of Research
Harcourt, Brace & World, Inc.

Robert Brode, Department of Physics
University of California (Berkeley)

Erwin Hiebert, Department of the History of Science
University of Wisconsin

Harry Kelly, Dean of the Faculty
North Carolina State University

W. C. Kelly, Director of Fellowships
National Research Council

Philippe LeCorbeiller
New School for Social Research

Thomas Miner
Garden City High School

Philip Morrison, Department of Physics
Massachusetts Institute of Technology

Ernest Nagel, Department of Philosophy
Columbia University

Leonard K. Nash, Department of Chemistry
Harvard University

I. I. Rabi, Department of Physics
Columbia University

Table III.

Partial List of Current or Recent Part-Time and Full-Time Staff and Consultants of Project Physics (affiliations indicated are those just prior to or during work period).

Andrew Ahlgren — *Maine Township High School, Park Ridge, Ill.*
David Anderson — *Oberlin College, Oberlin, Ohio*
Donald Armstrong — *American Science Film Association*
Theodore O. Benfey — *Earlham College, Richmond, Ind.*
Richard Berendzen — *Harvard College Observatory*
Joseph Bowles — *Oak Ridge Institute for Nuclear Studies*
Alfred Bork — *Reed College, Portland, Ore.*
Alfred Brenner — *Harvard University*
Robert Bridgham — *Harvard University*
Richard Brinckerhoff — *Phillips Exeter Academy, Exeter, N. H.*
Joan Bromberg — *Harvard University*
Stephen Brush — *Lawrence Radiation Laboratory, University of California at Livermore*
Michael Butler — *CIASA Films Mundiales, S.A., Mexico*
Douglas Campbell — *Harvard University*
Bobby G. Chambers — *Oak Ridge Institute of Nuclear Studies, Tenn.*
Robert Chesley — *Thatcher School, Ojai, Calif.*
John Christiansen — *Oak Ridge Institute of Nuclear Studies, Tenn.*
David Clarke — *Browne and Nichols School, Cambridge, Mass.*
Robert S. Cohen — *Boston University*
Brother Columban Francis F.S.C. — *Mater Christi Diocesan High School, Long Island City, N. Y.*
Arthur Compton — *Phillips Exeter Academy, Exeter, N. H.*
William Cooley — *University of Pittsburgh, Pittsburgh, Pa.*
Paul Cowan — *Hardin-Simmons University, Abilene, Tex.*
Charles Davis — *Fairfax County, Va., School District*
Elsa Dorfman — *Educational Services, Inc.*
Vadim Drozin — *Bucknell University, Lewisburg, Pa.*
R. T. Ellickson — *University of Oregon, Eugene, Ore.*
Walter Eppenstein — *Rensselaer Polytechnic Institute, Troy, N. Y.*
Herman Epstein — *Brandeis University, Waltham, Mass.*
Kenneth Ford — *University of California at Irvine*
Robert Gardner — *Harvard University*
Fred Geis — *Harvard University*
Owen Gingerich — *Smithsonian Astrophysical Observatory*
Stanley Goldberg — *Antioch College, Yellow Springs, Ohio*
Albert Gregory — *Harvard University*
Robert Haas — *Clairemont High School, San Diego, Calif.*
John Harris — *Hebrew University, Jerusalem*
Jay Hauben — *Harvard University*
Peter Heller — *Brandeis University, Waltham, Mass.*
Banesh Hoffmann — *Queens College, Flushing, N. Y.*
Gerald Holton — *Harvard University*
E. R. Huggins — *Dartmouth College, Hanover, N. H.*
Lloyd Ingraham — *U. S. Grant High School, Portland, Ore.*
Harald Jensen — *Lake Forest College, Lake Forest, Ill.*
John Johnson — *Worcester Polytechnic Institute, Mass.*
Ken Jones — *Harvard University*
Irving Kaplan — *Massachusetts Institute of Technology*
Robert Katz — *Kansas State University, Manhattan, Kans.*
Ashok Khosla — *Harvard University*
Walter Knight — *University of California at Berkeley*
Leo Lavatelli — *University of Illinois, Urbana*
Alfred Leitner — *Michigan State University, East Lansing*
James Lindblad — *Lowell High School, Whittier, Calif.*
Richard T. Mara — *Gettysburg College, Pa.*
Priya Mehta — *Harvard University*
Franklin Miller — *Kenyon College, Gambier, Ohio*
Jack C. Miller — *Claremont College, Pomona, Calif.*
Leonard Nash — *Harvard University*
Joseph Novak — *Purdue University, Lafayette, Ind.*
Thorir Olafsson — *Menntaskolinn Ad, Laugarvatni, Iceland*
Jay Orear — *Cornell University, Ithaca, N. Y.*
Costas Papaliolios — *Harvard University*
Jacques Parent — *National Film Board of Canada, Montreal*
Eugene Poorman — *University High School, Bloomington, Ind.*
Herbert Priestley — *Knox College, Galesburg, Ill.*
Edward M. Purcell — *Harvard University*
Gerald Rees — *Ann Arbor High School, Ann Arbor, Mich.*
Robert Resnick — *Rensselaer Polytechnic Institute, Troy, N. Y.*
Paul I. Richards — *Technical Operations, Inc.*
John Rigden — *Eastern Nazarene College, Quincy, Mass.*
Nickerson Rogers — *The Loomis School, Windsor, Conn.*
John J. Rosenbaum — *Livermore High School, Calif.*
William Rosenfeld — *Smith College, Northampton, Mass.*
F. James Rutherford — *Capuchino High School, San Bruno, Calif.*
Morton Schagrin — *Denison University, Granville, Ohio*
Guenter Schwarz — *Florida State University, Tallahassee, Fla.*
William Shurcliff — *Cambridge Electron Accelerator, Cambridge, Mass.*
M. Daniel Smith — *Earlham College, Richmond, Ind.*
Albert B. Stewart — *Antioch College, Yellow Springs, Ohio*
June Toulmin — *Nuffield Foundation, London, England*
Stephen Toulmin — *Nuffield Foundation, London, England*
Herbert Walberg — *Harvard University*
Fletcher G. Watson — *Harvard University*
Wayne Welch — *University of Wisconsin, Madison*
Richard Weller — *Harvard University*
Stephen Winter — *State University of New York at Buffalo*
Elizabeth A. Wood — *Bell Telephone Laboratories, Murray Hill, N. J.*

Past and Present Teacher Field Consultants

Roger A. Albrecht — *Osage Community Schools, Iowa*
Sam Ascher — *Henry Ford High School, Detroit, Mich.*
Ralph Atherton — *Talawanda High School, Oxford, Ohio*
William G. Banick — *Fulton High School, Atlanta, Ga.*
Rolland B. Bartholomew — *Henry M. Gunn High School, Palo Alto, Calif.*
Vinson Bronson — *Newton South High School, Mass.*
Leon Callihan — *St. Mark's School of Texas, Dallas*
Dora Clark — *Enloe High School, Raleigh, N. C.*
Arthur C. Compton — *Phillips Exeter Academy, N. H.*
David L. Cone — *Los Altos High School, Calif.*
Michael Dentamaro — *Senn High School, Chicago, Ill.*
Neil F. Dunn — *Burlington High School, Mass.*
Nicholas J. Georgis — *Staples High School, Westport, Conn.*
Richard H. Gerfin — *Simon's Rock, Great Barrington, Mass.*
Leon Goutevenier — *Paul D. Schreiber High School, Port Washington, N. Y.*
Walter G. Hagenbuch — *Plymouth-Whitemarsh Joint School System, Pa.*
Robert Henrich — *Kennewick High School, Washington*
John Jared — *John Rennie High School, Pointe Claire, P.Q.*
LeRoy Kallemeyn — *Omaha Benson High School, Neb.*
Benjamin Karp — *South Philadelphia High School, Pa.*
Harry H. Kemp — *Logan High School, Utah*
Merritt Kimball — *Capuchino High School, San Bruno, Calif.*
Donald Kreuter — *Brooklyn Technical High School, N. Y.*
Karol Kunysz — *Laguna Beach High School, Calif.*
Robert B. Lillich — *Solon High School, Ohio*
William Mehlbach — *Wheat Ridge High School, Colo.*
Glen Mervyn — *West Vancouver Secondary School, B. C.*
Kent D. Miller — *Claremont High School, Calif.*
James Minstrell — *Mercer Island High School, Washington*
James F. Moore — *Canton High School, Mass.*
Robert H. Mosteller — *Princeton High School, Cincinnati, Ohio*
William Naison — *Jamaica High School, N. Y.*
Henry Nelson — *Berkeley High School, Calif.*
Paul O'Toole — *Dorchester High School, Mass.*
Eugene A. Platten — *San Diego High School, Calif.*
James M. Reid — *J. W. Sexton High School, Lansing, Mich.*
Thomas Ritzinger — *Rice Lake High School, Wisc.*
Daniel Rufolo — *Clairemont High School, San Diego, Calif.*
Bernard Sachs — *Brooklyn Technical High School, N. Y.*
Rudolph Schiller — *Valley High School, Las Vegas, Nev.*
Myron O. Schneiderwent — *Interlocken Arts Academy, Mich.*
Sherman D. Sheppard — *Oak Ridge High School, Tenn.*
William E. Shortall — *Lansdowne High School, Baltimore, Md.*
Devon Showley — *Cypress Junior College, Calif.*
Sister Suzanne Kelly — *Monte Casino High School, Tulsa, Okla.*
Sister Mary Christine Martens — *Convent of the Visitation, St. Paul, Minn.*
Sister M. Helen St. Paul, O.S.F. — *Catholic High School of Baltimore, Md.*
Sam Standring — *Santa Fe High School, Calif.*
Robert T. Sullivan — *Burnt Hills-Ballston Lake Central School, N. Y.*
Thomas E. Thorpe — *West High School, Phoenix, Ariz.*
W. O. Viens — *Nova High School, Fort Lauderdale, Fla.*
Arthur Western — *Melbourne High School, Fla.*

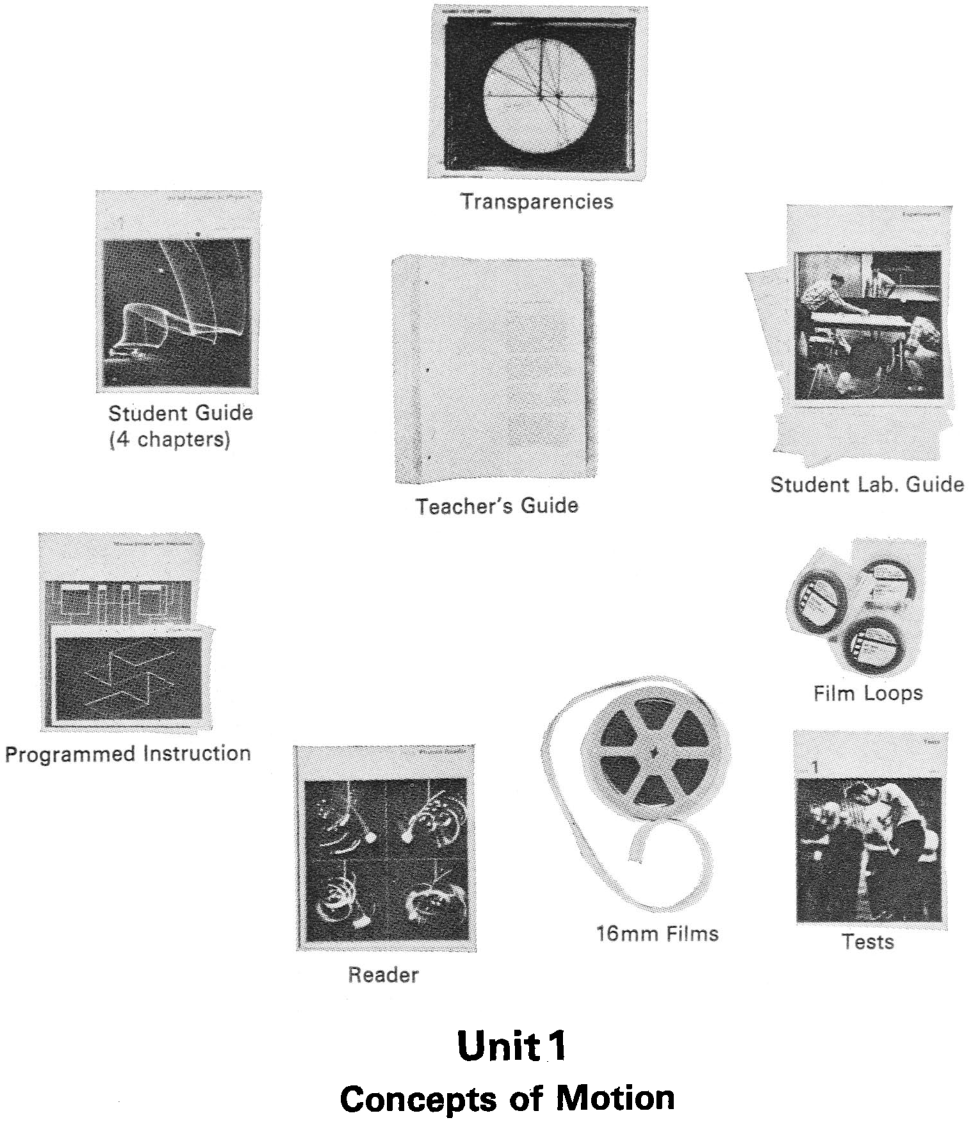

Fig. 3. Different components (media) making up a typical unit (Unit 1–*Concepts of Motion*).

Brief Survey of Materials and Aims

We now have a large stack of materials in various stages of accomplishment or design which the writers of other articles in this issue, with a little overlap, will describe.*

Like other major modern course revision projects, we have produced student guides (which used to be called texts), laboratory and demonstration equipment, laboratory manuals, tests, books of readings, films, loops, transparencies, programmed instruction booklets and teacher guides. Most of our materials have been tested and revised at least once. The different parts and the different media are designed to be used in a coherent way, as expressed symbolically in Fig. 3, which shows one example each of the components which make up Unit 1–*Concepts of Motion*, the first of the basic six units of the course. Our course has progressively moved away from the idea that a text must be the major source of input to the student. Many detailed discussions turned out to be much better handled through film loops, through programmed instruction, or through the laboratory. Therefore, the burden does not remain with the printed word of the text where that turned out to be *not* the best channel for learning. Dr. Rutherford and others write in more detail about these components and the systems approach to their use.

My chief topic is the material content of the Project Physics course, and the objectives of the course. They belong together, because the material content reflects the aims.

If I were to select from the many objectives which urge themselves on any curriculum maker today, I would put at the head of the list these four. First, we wish to create a coherent, tested course for use on a national scale alongside the others that have been developed previously; but it is to be a course that accentuates those aspects of physics and pedagogy which have so far not been prominently incorporated into course developments in physics on the high school level, although they are widely held to be desirable. We can hope, in

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* Other details will be found in the five *Newsletters* we have published from time to time. Copies are free on request by writing to the *Newsletter* Editor, Harvard Project Physics, Pierce Hall, Harvard University, Cambridge, Mass. 02138. That over 18,000 persons have written for information indicates the intense interest we have encountered.

this way, to provide variety of choice in the physics teacher's arsenal.

Second, we hope to help stem the decline in proportionate enrollment in physics at the high school level—a decline which in fact is now reaching into the college years. Professor Watson writes on page 212 about this deeply troublesome situation, one which is nothing less than a national educational emergency.

Third is the obvious and necessary decision to provide teachers with all the necessary aids for teaching good physics in realistic classroom situations as they now exist and are likely to continue to exist, e.g., a single one year course in senior high school. Here we define *good physics* in the widest, most humanistic way possible, rather than in preprofessional terms alone.

And fourth, our course development requires thinking entirely afresh through some quite basic questions, such as the new role of the teacher and his involvement with the class, the new desire to allow greater diversity and flexibility, and the new opportunities opened up by the developing technology of education. Therefore, we have been evolving new guide lines that may help curriculum development in general in this country.

Let us examine some of these aims in more detail to see how they can help us decide on the structure and content of the course.

The need for new physics courses

The need for a second nationally supported physics course has often been expressed by teachers, by officials of the National Science Foundation when they speak before Congressional Committees, by authors of the PSSC course, and by others. As was the case in high school chemistry, biology, and mathematics, there is no doubt that the physics profession, too, must produce more than one model for use in the physics classrooms of this large country. We are imaginative enough and rich enough to demand this of ourselves—above all, in the field of education. This is surely in the best American style, and the argument is greatly strengthened when we take a look at the statistics of physics enrollment.

By the fall of 1963, when the scientists and educators brought together by the National Science Foundation called for new groups to create new high school courses, it had become clear that physics continued to be the only science high school students are avoiding in larger and larger proportions. According to U.S. Office of Education surveys, the fraction of senior high school students taking any physics course has steadily declined and has now dipped to less than 20% at last count; this means that out of a school population of about two and one-half million seniors, over two million each year are taking no introductory physics course of any kind in senior high school. Indeed, in the most recent survey (for 1964-65) by the U.S. Office of Education, which has just been released,* we find that out of a total of 2,472,000 public school students in the twelfth grade, 484,600 are in any kind of introductory physics course in senior high school; of these, 384,700 are in Traditional Physics and 99,900 in PSSC. (Another 41,600 are in Advanced Physics.) Thus a total of only 4% of all the seniors in public high school had taken the PSSC physics course in 1964–65, splendid though the course is for the intended student group. Obviously a great deal of work remains to be done by all physicists and teachers interested in good education. In the light of the data on actual enrollment, it is clear that nothing is more dangerous to the cause of improving high school physics than a widespread but false feeling that no major problems are left in this area. *And for this reason let me emphasize that Project Physics is in no way to be thought of as an alternative or rival to PSSC. We shall need both of these, and many other good courses, to meet the needs of variety and volume of physics classes.**

We have better reasons for wanting to attract more students into a high school physics course than to reverse a drooping curve of statistical enrollment data. Once we understand *why* so many students are now turning their backs on currently available physics courses, we can begin to understand more clearly what an attractive and meaningful course must be like.

There are two main arguments to make. First, important decisions are made by a student in the senior year in high school. A student should be able to discover if he or she has talent and inclination for the physical sciences; we do not want to turn our backs on future scientists. But equally important, a good physics course in senior high school is, in our view, badly needed by students at the other end of the spectrum, by those who will not go to college at all. To be sure, neither our course nor any single other course should hope to reach all students; and particularly for the lower half of this group, there should be far more curriculum development work done than we or any other existing group is capable of handling. Precisely because the need is so great and the task so difficult, several new and different attempts are now needed.

We have here a serious social mission. In the years ahead, high school graduates without sufficient science education may well find themselves standing on the job lines next to those who have no high school diploma at all. Now that jobs of the more menial kind are being eliminated at the rate of about 100,000 a year, even the simpler industrial or business jobs in our more and more technological society will require some knowledge of the physical sciences and of the elements of scientific thinking. Without this, young people will find it increasingly difficult to profit from in-plant training, from technical home study, and all the other opportunities which in the 1970's and 1980's will allow them to be adequate wage earners and, indeed, citizens and parents.

An equally important mission lies with another group which now says *no* to all existing high school physics courses: the larger and larger numbers who go on to college and who there concentrate in the humanities or

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* *Preliminary Data on Enrollment in Science and Mathematics in U.S. Public High Schools, 1964-1965,* released November 1966, by the National Center for Educational Statistics, Washington, D.C., through the National Research Council. These data are published by permission of the Assistant Commissioner of Educational Statistics, USOE.

* The decline in college physics students is another problem, and may well be a related one. The number of bachelor's degrees in physics granted to men leveled off in 1961–62 at about 5600 per year (2.16% of all bachelor's degrees granted that year to men in the U.S.). In 1965–66 the figures were 5517 (1.76%) and for 1969–70 the projected figures are down to 4500 (1.0%). Source: *Physics Manpower 1966, Education and Employment Statistics* (AIP, 1966).

social studies. They also have been avoiding college physics courses, and usually take at most a general college science course, with some reluctance and little benefit.

We believe it is necessary and possible to reach students of this sort before they get to college, and to show them that physics is neither an isolated, bloodless body of facts and theories with mere vocational usefulness, nor a glorious entertainment restricted to an elite of specialists. Precisely these students should realize that what has been achieved in physics has sooner or later influenced man's whole life. To be ignorant of physics may leave them unprepared for their own time. They can be neither participants nor even intelligent spectators in one of the great adventures. It is as if an Athenian freeman did not know the Greek language and so could not follow, at least to some extent, the meaning of what was being argued at the Agora and the Akademia, what was being done at the Olympic Games, or at any of the great rituals and festivals of this time. In short, I agree with I. I. Rabi who has often said that physics now lies at the "core of the humanistic education of our time".*

This does not mean we must make a *soft* physics course, or a course which does poetry instead of physics. On the contrary, it can mean a physics course that accentuates just those elements which characterize the most thoughtful, persisting, fundamental achievements in physics itself, from Galileo to our day. Indeed, this aim is along the same lines as that expressed by a committee of the AIP Pre-College Physics Project, which recommended that more than one type of physics course should be available in schools; the second suggested course, they wrote, "would not be a regular physics course, watered down or dressed up, but rather a serious course, thoughtfully designed to fill the needs of today's educated citizen, for whom this may be the only physics course in his educational experience".†

During the past three or four years articles, editorials, and letters to the editor in publications such as THE PHYSICS TEACHER and *Physics Today* have indicated that many people support the idea that good physics on the introductory level should include physics taught from a humanistic point of view. This opinion is shared not only by many physicists, but it also coincides precisely with the expressed interests of physics teachers themselves. Thus, in March 1965 THE PHYSICS TEACHER, a survey reported the replies of 1380 high school physics teachers. Of them 79% thought that high school students stay away from physics because in their schools the courses as now given do not suit their abilities and desires; 91% said also that a physics course with a cultural component is needed by nearly everyone.

Teaching good physics

High on the list of aims must of course be a desire to teach "good physics", or "what physicists would recognize as good physics", to give this phrase an operational meaning. But this laudable aim can be a trap. If the goal is not faced realistically, the other three goals will become unachievable. I am thinking here of the father of a student in one of our trial schools who last year came in with a stack of *Physical Review* issues; as a physicist working in a government laboratory, he demanded that the students in his daughter's class should get "the real stuff". The fact is that the pyramidal structure of physics, so beautiful and almost unique to our field, makes it practically impossible to talk in honest detail about most of the actual problems on which physicists are now working; at least this is true for the introductory course for the average student in high school or, for that matter, in college. Therefore, except for rare and specially prepared cases, good physics in high school cannot be defined as a panorama of the details of contemporary work.

But even a piece of older knowledge that is still recognized as good physics by physicists would, in most instances, require a major effort, perhaps many months, in order to get the story right; for example, why the sky is blue, why conductors sometimes obey Ohm's Law, why solid bodies sometimes obey Hooke's Law, why water usually freezes at a fixed temperature and pressure. These *are* good questions; they are often asked at the oral examinations for Ph.D. candidates. We have preferred not to concentrate on such a catalog of well-established items and pieces in Project Physics because we believe they do not let us tell a coherent story, and because in fact we cannot do justice to them in the time available without continually diluting the physics.

Nor do we want to go down another road which used to be more fashionable many years ago than it is now, namely, to find those few pieces of physics which *can* be presented in a more or less complete and self-contained way. This desire used to lead some of the old books to present physics as a disconnected set of little pieces, typological lists, and idealized cases that have no other merit than that they allow the teacher to keep closed all the doors to the real difficulties. This was the era of physics courses in which Atwood's machine, the Wheatstone Bridge, Archimedes' principle, and the lens equation were triumphant—the lowest common denominator which still turns up all too frequently in national tests. I do not think we have helped a student who has studied this sort of thing so well that he can answer all the obvious questions at the end of the course. Such a student has not begun to see what physics is all about if, in this pursuit, he has seen none of what is sometimes called the general education aspect or humanistic aspect of physics, i.e., the sweeping power of a few fundamental laws, the use and limit of models in physics, the use and limit of mathematical formulations, the persistence of great themes, such as atomism, in the face of continual disproof of older models, the beautiful and sometimes awesome story of how real people made physics; in short, if he has not encountered those very characteristics of physics which have given this subject its centrality, both in science and in the history of ideas. Good physics is not "one darn thing after another", not even one beautiful piece of physics after another. Rather, good physics is a sequence of related ideas whose pursuit provides one with the cumulative effect of an even higher vantage point and more encompassing view of the workings of nature.

When seen in this way, physics must be presented not only as a science with interesting concepts and predictive

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* The recommendations of the Educational Policies Commission of the NEA, entitled *Education and the Spirit of Science* (NEA, Washington, D. C. 1966) are closely related to this point of view, as is the NSTA document, *Theory Into Action in Science Curriculum Development* (NSTA, Washington, D. C. 1964).

† Preliminary report of the Advisory Committee of the Pre-College Physics Program of the American Institute of Physics 1966.

Table IV. Tables of Contents of Student Guides, Units 1 through 6, Experimental Version 1966

Unit 1 – Concepts of Motion

PROLOGUE

CHAPTER 1: THE LANGUAGE OF MOTION: POSITION, SPEED, ACCELERATION

- In nature, motion is everywhere
- From nature into the laboratory
- Uniform straight–line motion
- Specifying position
- A definition of uniform speed
- Graphing motion
- The concept of average speed during nonuniform motion
- The concept of instantaneous speed during nonuniform motion
- Acceleration

CHAPTER 2: FREE FALL—GALILEO DESCRIBES MOTION

- The Aristotelian theory of motion
- Galileo and his times
- Galileo's *Two New Sciences*
- Why study the motion of freely falling bodies
- A definition of uniform acceleration
- Galileo's hypothesis cannot be tested directly
- Looking for logical consequences of Galileo's hypothesis
- Galileo turns to an indirect test
- How valid was Galileo's procedure
- What is the magnitude of the acceleration of freely falling bodies

CHAPTER 3: SOME COMPLEX MOTIONS

- What are complex motions
- The question of direction: vectors
- Projectile motion
- The superposition principle
- What is the path of a projectile
- Galilean relativity
- Circular motion
- Describing uniform circular motion
- Centripetal acceleration
- The geometric relationship between velocity and acceleration
- The magnitude of centripetal acceleration
- The motion of earth satellites
- What about other complex motions

CHAPTER 4: THE BIRTH OF DYNAMICS—NEWTON EXPLAINS MOTION

- The beginning of dynamics
- Explanation and the laws of motion
- The first law: the concept of force appears
- The Aristotelian view
- The principle of inertia
- The significance of the first law of motion
- The second law of motion
- Testing the second law of motion
- Units of mass and force
- Using the second law to explain motion
- Gravitation and the second law
- Newton's third law
- The third law and interacting objects
- The unity of the three laws

EPILOGUE

Unit 2 – Motion in the Heavens

PROLOGUE

CHAPTER 5: WHERE IS THE EARTH?—THE GREEKS' ANSWERS

- Motions of the sun and stars
- Motions of the moon
- The wandering stars
- Plato's problem
- A first solution
- A sun–centered solution
- The geocentric system of Ptolemy

CHAPTER 6: DOES THE EARTH MOVE?—THE WORKS OF COPERNICUS AND TYCHO

- The Copernican system
- New conclusions
- Arguments for the Copernican system
- Arguments against the Copernican system
- Historic consequences
- Judging a theory
- Tycho Brahe
- Tycho's observations
- Tycho's compromise system

CHAPTER 7: A NEW UNIVERSE APPEARS—THE WORK OF KEPLER AND GALILEO

- The abandonment of uniform circular motion
- Kepler's second law
- Kepler's first law
- Using the first two laws
- Kepler's third law
- The new concept of physical law
- Galileo's viewpoint
- The telescopic evidence
- Galileo's arguments
- The opposition to Galileo
- Science and freedom

CHAPTER 8: THE UNITY OF EARTH AND SKY—THE WORK OF NEWTON

- Introduction
- A sketch of Newton's life
- Newton's *Principia*
- A preview of Newton's analysis
- Motion under a central force
- The inverse–square law of planetary force
- Law of Universal Gravitation
- The magnitude of planetary force
- Testing a general law
- The moon and universal gravitation
- Gravitation and planetary motion
- The scope of the principle of universal gravitation
- The moon's irregular motion
- The tides
- Comets
- Relative masses of planets and the sun
- The actual mass of celestial bodies
- Beyond the solar system
- Gravitational fields
- Some influences on Newton's work
- Newton's place in modern science

Unit 3 – Energy

PROLOGUE

CHAPTER 9: THE CONSERVATION OF MASS

- Conservation laws
- Is weight conserved?
- Distinction between weight and mass
- Is mass really conserved?

CHAPTER 10: THE CONSERVATION OF MOMENTUM AND MECHANICAL ENERGY

- Conservation of momentum
- Views of Descartes and Newton on the quantity of motion in the world
- Kinetic and potential energy
- Leibniz and the principle of conservation of energy
- Internal energy and heat
- Work and energy
- Forces that don't do any work
- Summary of the principles of mechanics

CHAPTER 11: HEAT AND WORK

- Heat and work
- The Savery and Newcomen engines
- Improvements and applications of steam engines
- The Industrial Revolution and its social and cultural effects
- Measuring the performance of steam engines
- The discovery of the law of conservation of energy
- Energy in biological systems
- The Second Law of Thermodynamics and the dissipation of energy

Continued

Table IV. Continued

CHAPTER 12: A GAS AS A MECHANICAL SYSTEM
- Explanations based on the motions of small invisible particles
- Air pressure
- The Boyle–Newton theory of gas pressure
- Daniel Bernoulli and the kinetic theory of gases
- The ideal gas law
- Heat and molecular kinetic energy
- Expansion into a vacuum and the mechanical equivalent of heat
- Making the kinetic theory more realistic
- Distribution of molecular speeds and fluctuations
- Molecular magnitudes
- The dissipation of energy and Maxwell's demon
- Criticisms of kinetic theory based on the reversibility and recurrence paradoxes

EPILOGUE

Unit 4 – Waves and Fields

PROLOGUE

CHAPTER 13: CHARGES AND CURRENTS
- The curious properties of lodestone and amber
- Some electrostatic experiments
- Magnetic and electrical force laws
- Electrical currents
- Currents act on magnets
- Magnetism is an electrical effect

CHAPTER 14: FIELDS
- The concept of *field*
- Representing gravity as a force field
- Electric force fields
- Adding fields
- Mapping force fields
- The concept of a *potential* field
- Electric potential
- Electric potential difference and current
- Electric potential difference and power
- Mapping potential fields
- Magnetic fields
- The path of a charged body in a magnetic field

CHAPTER 15: WAVES
- Introduction
- What are waves?
- The speed of propagation
- Energy transport and communication
- The superposition principle
- Reflection
- Periodic waves
- Refraction
- Interference patterns
- Diffraction
- Standing waves

CHAPTER 16: ELECTROMAGNETISM AND LIGHT
- Introduction: review and preview
- Oersted and the discovery of electromagnetism
- Quantitative studies of the magnetic effects of electric currents
- Faraday and the magnetic induction of electric current
- Maxwell's Electromagnetic Theory
- Some properties of light
- The particle and wave theories of light
- The triumph of the wave theory of light in the nineteenth century
- Light and the electromagnetic spectrum
- The Ether—a serious problem

EPILOGUE

Unit 5 – Models of the Atom

PROLOGUE

CHAPTER 17: THE CHEMICAL BASIS OF ATOMIC THEORY
- Dalton's atomic theory and the laws of chemical combination
- The atomic masses of the elements
- Other properties of the elements: valence
- The search for order and regularity among the elements
- Mendeleev's periodic table of the elements
- The modern periodic table
- Electricity and matter: qualitative studies
- Electricity and matter: quantitative studies

CHAPTER 18: ELECTRONS AND QUANTA
- The problem of atomic structure: pieces of atoms
- Cathode rays
- The measurement of the charge of the electron: Millikan's experiment
- The photoelectric effect
- Einstein's theory of the photoelectric effect: quanta
- X rays
- Electrons, quanta and the atom

CHAPTER 19: THE RUTHERFORD–BOHR MODEL OF THE ATOM
- Spectra of gases
- Rutherford's nuclear model of the atom
- Nuclear charge and size
- The Bohr theory: the postulates
- The Bohr theory: the spectral series of hydrogen
- Stationary state of atoms: the Franck–Hertz experiment
- The periodic table of the elements
- The failure of the Bohr theory and the state of atomic theory in the early 1920's

CHAPTER 20: NOTES ON MODERN PHYSICAL THEORIES
- Special relativity theory
- The Compton effect
- DeBroglie's hypothesis and the dual nature of matter
- Quantum mechanics
- Uncertainty principle
- Wave–particle dualism and probability

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APPENDIX

Unit 6 – The Nucleus

PROLOGUE

CHAPTER 21: RADIOACTIVITY
- Becquerel's discovery
- Other radioactive elements are discovered
- The properties and nature of the radiations: α, β, γ
- Radioactive transformations
- Decay constant; activity, half–life

CHAPTER 22: ISOTOPES
- The concept of isotopes; the displacement rules
- The mass–spectrographic separation of isotopes
- The stable isotopes of the elements and their relative abundance
- Atomic masses

CHAPTER 23: THE NUCLEUS
- The problem of the composition and structure of the atomic nucleus
- The proton–electron hypothesis of nuclear structure
- The discovery of artificial transmutation
- The discovery of the neutron
- The proton–neutron theory of the composition of atomic nuclei
- The need for particle accelerators
- Nuclear reactions
- Artificially induced radioactivity

CHAPTER 24: NUCLEAR ENERGY; NUCLEAR FORCES
- Conservation of energy in nuclear reactions
- Energy of nuclear binding
- The mass–energy balance in nuclear reactions
- Nuclear fission: its discovery
- Nuclear fission: practical applications and other consequences
- Nuclear fusion
- Nuclear forces and nuclear models
- Elementary particles
- Biological and medical applications of nuclear physics

EPILOGUE

powers, but also a science which has peculiarly, and perhaps uniquely, a structure that connects these concepts; and in addition one wants to show the student occasionally the roots and humanistic consequences of the science which, in most instances, will touch and concern him only in this way. A few years ago I tried to build this point of view into two college-level texts; my own interest in starting Project Physics for high schools and junior colleges was triggered by the realization that the same general point of view is in fact appropriate for the introductory course at any level, whether senior high school or college.

Far be it from me to claim, at this halfway point, that we have fully succeeded. Much alchemy is still needed to change the base metal. But this is our warrant and our vision, and hence defines the framework of our efforts.

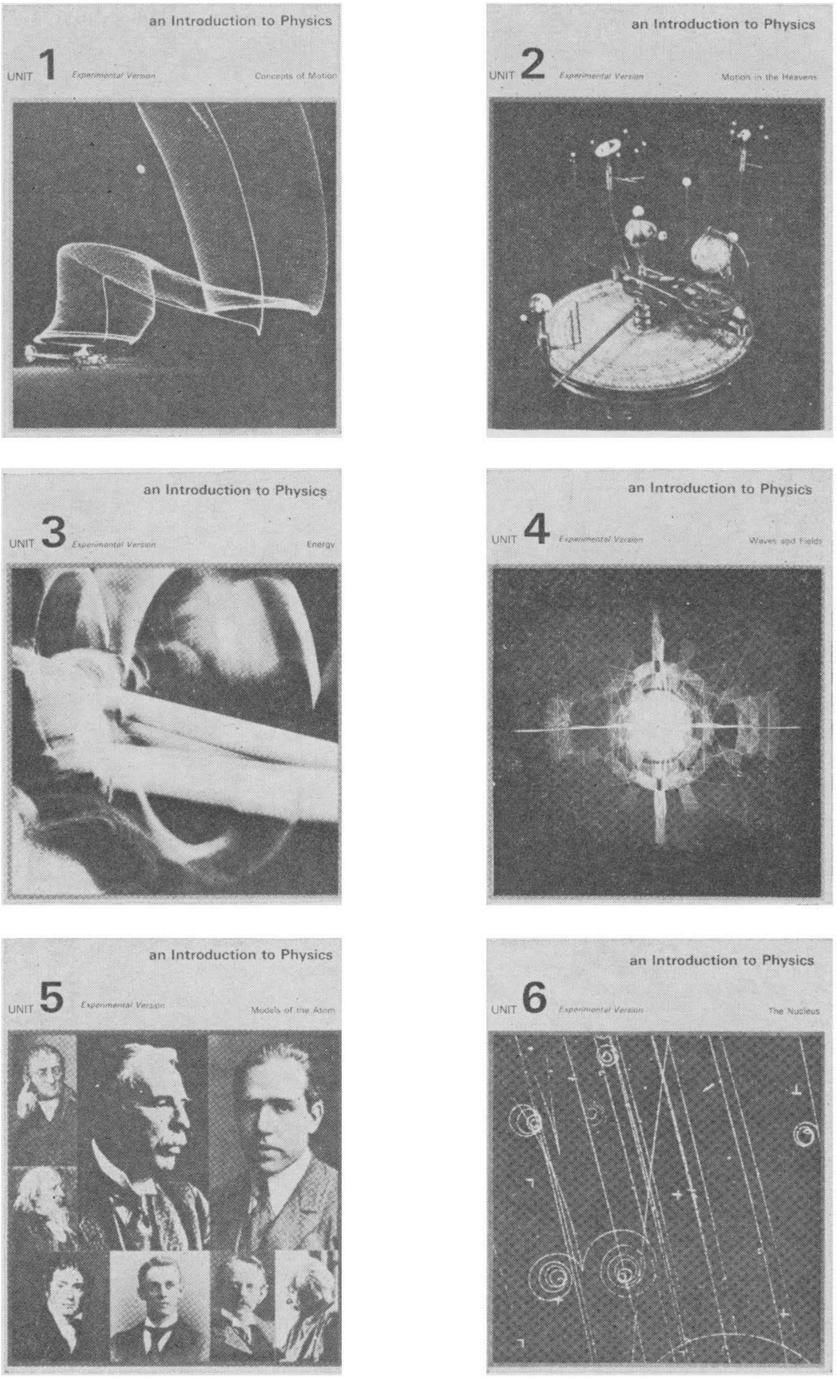

Fig. 4. *Student Guides* (texts) for the six basic Units of Project Physics.

Survey of contents

We have divided the basic course material into six units, each of which is meant to occupy the average class for one to two months. The *Student Guide* for Unit 1–*Concepts of Motion* (top left, Fig. 4 and Table IV) has four chapters: The Language of Motion; Free Fall; Some Complex Motions; and The Birth of Dynamics —Newton Explains Motion. The main theme is how to know a great deal while being practically ignorant of details—possibly the most successful trick which physicists have devised. Now this material is proverbially difficult for beginning students, and the course would be pedestrian if it only tried to drill the use of some conceptual tools, such as the intuitive concept of instantaneous velocity, the use of vectors, etc. But here we have a chance to let students learn about motion not merely by launching rockets, using an inexpensive air track, and computing periods of lunar satellites; but also we need not pass up the chance to repeat the experiments which Galileo has so lovingly described. By reading Galileo's own eloquent words, and using his techniques, one can get a sense of the development of ideas, and the realization that science always changes and sometimes comes to important turning points. This is also an occasion for arguing whether Galileo could really have done what he said he did with the experimental accuracy he claimed.

The frequent use by the student, in his *Student Guide* and the laboratory, of stroboscopic photographs is, in many ways, a quite symbolic exercise: from "observations" he can obtain first the description of motion and then an explanation in terms of forces. With this technique and instrument, the complex situation is narrowed down to essential pinpoints of light; and after this abstraction a further abstraction becomes possible, that of transferring the play of events to the world of mathematics. Then we can return to the world of real bodies, which we now can master so much better with the concepts of kinematics and dynamics.

Unit 2 applies what Unit 1 has prepared. Entitled *Motion in the Heavens,* Unit 2 deals with the dynamics of our planetary system. But in this unit we can do what in other units we have not so much time for, namely, set the achievement of an understanding of the motions

Table V.
Sample Page
From Teacher's Guide

ORGANIZATIONAL Worksheet for CHAPTER 3

TEXT SECTION	rough time suggestion for text treatment	EXPERIMENTS	DEMONSTRATIONS	TEACHING AIDS	STUDENT ACTIVITIES	READER ARTICLES	PROBLEMS
3.1 What are complex motions?	one day				A3.1 MAKING HARMONOGRAMS		
3.2 The question of direction: vectors.			D3.2a VECTOR ADDITION OF VELOCITY D3.2b NON-COMMUTATIVITY OF ROTATIONS	T3.2 TRANSPARENCY: VECTOR OPERATIONS		I.3	1,2,
3.3 Projectile motion	one day			T3.3 TRANSPARENCY: PARABOLIC PROJECTILE MOTION	A3.3 PHOTOGRAPHING PROJECTILE MOTION	I.6	
3.4 The superposition principle.			D3.4 STROBE ANALYSIS OF SUPERPOSITION PRINCIPLE FOR FREE FALL	T3.4 TRANSPARENCY: PARABOLIC PROJECTILE MOTION			3,7,
3.5 What is the path of a projectile?		E3.5* TRAJECTORIES	D3.5 SIMULATION OF A PARABOLIC PATH	T3.5 TRANSPARENCY: PARABOLIC PROJECTILE MOTION	A3.5a LAUNCHING PROJECTILES A3.5b CALCULATING SPEED OF A STREAM OF WATER		
3.6 Galilean relativity.	one day		D3.6a FRAMES OF REFERENCE D3.6b INERTIAL VS. NON-INERTIAL REFERENCE FRAMES D3.6c MONKEY-GUN EXPERIMENT	T3.6a FILM LOOP: A MATTER OF RELATIVE MOTION T3.6b PSSC FILM: FRAMES OF REFERENCE T3.6c TRANSPARENCY: FREE FALL T3.6d TRANSPARENCY: PARABOLIC PROJECTILE MOTION			5, 6,
3.7 Circular motion.			D3.7 GENERATING A CYCLOID	T3.7 PROGRAMMED UNIT: "ANGULAR MEASURE"			
3.8 Describing uniform circular motion.			D3.8 EFFECTS OF ROTATING REFERENCE FRAMES		A3.8 MEASURING PERIOD OF VARIOUS MOTIONS		

in our planetary system in its historic context as well as raise such methodological questions as how one is to decide between rival theories. Therefore, the chapter headings of the *Student Guide* for Unit 2 are as follows: Where is the Earth?—The Greeks' Answers; Does the Earth Move?—The Works of Copernicus and Tycho; A New Universe Appears—The Work of Kepler and Galileo; The Unity of Earth and Sky—The Work of Newton.

At the end of this Unit, particularly through the *Reader* for this Unit, the student can go beyond the scientific aspect of the Newtonian synthesis. Newton's work helped to bring a wholly new sense of intellectual possibilities into the age which he shaped: the mind of man now seems capable of understanding all things in heaven and earth. To a degree, what we think today and how we run our affairs is still based on these events of three centuries ago. And to a degree the physics of today will do the same for future times. We therefore suggest to the student that, if he understands the way in which science influences some one chosen part of history, he will be better prepared to understand how the science of yesterday and today influences the world in which he lives.

After the intellectual reach into the sky in Unit 2, Unit 3 is the triumph of the mechanistic point of view throughout physics: the laws of conservation of mass and momentum; mechanical energy and the first law of thermodynamics (with the second law to be treated only qualitatively); kinetic theory, with some explicit attention to the great power and limits of the model, and the new theme of our ability to master chaos; finally, going further from the discussion of two–body problems, a chapter on mechanical waves (in the current revision being brought forward from Unit 4 to Unit 3).

A number of themes can be touched upon in Unit 3 in addition to the obvious ones. One is symmetry, both the spatial and the temporal aspects. Another is the connection between science and technology. In discussing the laws of thermodynamics, we can grasp the chance to make the point (in not many pages of the *Student Guide* and in the *Reader*) that the heat engine, like many other technical by-products of scientific work, is not a device operating in a vacuum of social consequences. Rather, the heat engine helped to alter the structure of Western society during the Industrial Revolution, and affected the imagination of poets and theologians no less than of mathematicians.

We are now ready for the treatment of electricity, magnetism, and light—in short, the failure of the mechanistic view and the beginning of a new physics. This is the subject of Unit 4, which deals with fields at rest, fields in motion, and light as an electromagnetic wave phenomenon.

Unit 5 deals with the models of the atom: the chemical basis of atomic theory; electrons and quanta; the quantum–theoretical model of the atom; and some introduction to subsequent theories, particularly wave–particle dualism.

Unit 6 is on the nucleus: radioactivity; isotopes; the nucleus and elementary particles; nuclear energy and nuclear forces.

Again from time to time in all these Units, whether in the *Student Guide* or in the *Reader* or through the *Teacher's Guide*, occasions occur where the connection between physics and other sciences or other endeavors can be pointed out. And this is only being true to the real state of affairs. Physics by itself, without ties to anything else, is an invention of its most hostile foes and its most single–minded protagonists. One cannot survive a single day on physics alone in a real physics laboratory. One needs mathematics and chemistry and metallurgy and technology—and indeed the commitment of society as a whole . . . a point about which physicists are bound to begin to wonder more and more as time goes on, if present indications are true.

These six Units make up the *basic* or main line course. It should be remembered that each Unit is to be conceived as a set of materials of the same kind as shown in Fig. 3 for the first of these Units, and that each is meant to occupy the average class from one to two months. Consequently, we have produced six "texts" or *Student Guides* of four chapters each, plus equipment, etc., and above all six *Teacher's Guides* with extensive discussion of all the materials, e.g., of the laboratories and how they are to be integrated with reading and other work, plus additional background in physics (or history of science and the like) and a day-to-day program (see Table V) for those teachers who prefer to use it.

Most teachers, certainly after the initial period of use, should be able to finish the six basic Units, with ample time left to add one or more supplemental Units. We have made a start on several such supplemental Units (see Table VI) and hope for a total of some twenty, from which the teacher can choose freely, on condition that he has fully and thoroughly covered the material in the six basic Units. This combination of providing a manageable basic course and yet having up to one third of additional material in full control of the teacher's own choice (which may be different materials for different members of the class) yields a model in which the decisions are far more teacher-centered than has sometimes been the case.

Principles of selection

The content of the basic Units shows that about one-third of the content refers to basic twentieth-century concepts. This fraction can be increased to two-thirds with proper choice of supplemental Units. I should say a word about the selection principles which we have been using

Table VI. Titles of Proposed Supplemental Units to Student Guides

Accelerators and Reactors
Special Relativity
Thermal Motion
Astronautics and Space Physics
Particle Physics
Discovery in the Physical Sciences
Biophysics
Cosmogony
The Physics of Everyday Optics
Diffraction: Observing the World Through Small Openings
Chemistry and Physics
Radioisotopes and Their Applications
Social Consequences of Scientific Technology
Physics and Engineering
The Physics of Transportation
The Physics of Music
The Physics of Crystals
Physics and Electronics
Physics and Sports
Science and Literature
The Eye
The Ear
Physics for the Airplane Passenger

for making these decisions on content. Such principles have been laid down and reaffirmed repeatedly for physics courses, and there is not much disagreement in the profession concerning the list of fundamental ideas and theories. Despite the infinite proliferation of detail, the basic physics remains manageable in a one year course (although it would be far better to have more than one year). The list of main concepts follows closely along the lines adopted some years ago at the Carleton Conference, reaffirmed at the 1964 Boulder Conference and on other occasions, and which is incorporated in a number of existing and well-regarded textbooks of introductory physics.*

We have made some efforts to ensure that any concept or theme of physics that enters the course in its final form is, in fact, one needed either because it prepares for the understanding of a later part of the course or because the concept or theme is so significant that it makes an appearance repeatedly. The use of modular concepts in physics is one of the trademarks of our science. For example, the ideas of projectile motion turn up in Unit 1, first in kinematics and then in dynamics, again in Unit 2 in the calculation of the fall of the moon from its inertial motion, in Unit 3 in treating the conservation laws, in Units 4 and 5 in connection with e/m measurements and mass spectrographs, and it can turn up again in Unit 6 where we have a chance to speak about the design of the linear accelerator that takes into account the fall of the electron during its two mile trajectory.

We find we must continually guard against bad habits, such as reverting to fascinating encyclopaedic detail, or to material which is too advanced for most students and teachers. We also must continually guard against the bad habits we learned in our book-oriented schools and must try to make proper use of other media, starting with the best possible illustrations and designs of the book materials themselves. We must remember that those who are deaf to physics may not be blind to physics, or may be kinesthetically sensitive to experience with laboratory equipment. Teaching ideas through only one medium, and preferably through the printed word, is no longer sound, either pedagogically or technologically.

To put it bluntly, we must have the courage to say *no* to the pressures of pregraduate school professionalism. The course must be up-to-date precisely by avoiding quickly obsolescent materials by attending to those concepts and ideas which are so basic that they are likely to be at the foundations of physics for a very long time in the future.

A word should also be said about the place of history of science in a course such as this. Nobody in the Project has favored either a strictly historical order, or the use of the history of science for its own sake. Rather, we have followed the precept that a physics course can use the history of science occasionally as a pedagogic aid without becoming itself a course in the history of physics. As in the case with the other nonphysics materials, a little goes a long way. If I have stressed historical examples in this article it is because even this little is so much more than is usually found in an introductory course at the high school level.

New Directions for Science Curricula

Just as important as producing a specific physics curriculum, and perhaps even more so in the long run, is our fourth aim of helping to provide new guidelines for curriculum development in general for the late 1960's and the 1970's. It is, after all, high time for that! A decade has gone by since Sputnik helped spark a first round of curriculum development. Educationally speaking, this was a whole generation ago. That work was carried out in the ideological setting of that time, which was in many ways totally different from today's. We have, for example, more knowledge of and different attitudes about schools, teachers, and students. Thus, we have begun to respect far more the role of teacher as collaborator in making curriculum development work in the classroom on his own terms, and we have become more interested in considering the different needs of different students in the same classroom.

We have different assumptions of what is and is not feasible or desirable for schools to do; for example, we would not today develop a curriculum that caters only to the intellectual elite. There is also now, happily, a different situation with respect to the availability of money for school equipment (it is larger by a factor of about 100), and of the participation of industry. We have also learned a lot in ten years about the limits of effectiveness of the hopes and dreams of curriculum makers, and one aspect of that is a new realization that a detailed scholarly evaluation of the achievement and failure of any curriculum development in the various circumstances of real life is a prime responsibility of the curriculum group, if not of an independent agency. In short, the time has come for a new educational deal in the cooperation of schools, teachers, curriculum groups, sponsoring agencies, industry, and teacher-training institutions. While we feel of course deeply indebted to the pioneering work in curriculum development by such groups as BSCS, CBA, CHEMS, and PSSC, we fully expect that Project Physics, the first of the new, second-generation science curriculum developments for senior high school, can help to indicate the elements of this new deal.

We hope to show the way particularly in two respects, which have been implicit in this discussion: by refining and accentuating the role of the teacher, and by building into the system enough flexibility so that this course can be a model for coping with diversity.

The teachers we have been working with have in most cases been ingenious and knowledgeable. Several are with us all year in Cambridge, and many more are working with us each summer. In addition, we have had continuous contact with our teachers in the field. They are coming back for feedback conferences, they are being visited, and they keep in touch with us by mail continually on a well-regulated basis of feedback processing. They are doing a wonderful job in view of the shocking working conditions of high school teaching generally.

But the profession of physics teaching as a whole is in trouble, and college physicists should be actively concerned about it. As an AIP survey recently showed, less than 10% of the 17,000 high school teachers who are teaching some physics classes are occupied fully with the teaching of physics.* Two-thirds of them had fewer than eighteen college-physics semester hours. This is far

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* "Improving the Quality and Effectiveness of Introductory Physics Courses", Am. J. Phys. **25**, 417 (1957); and M. Correll and A. A. Strassenburg, Editors, *The Proceedings of the Boulder Conference on Physics for Nonscience Majors* (Commission on College Physics, Ann Arbor, 1965).

* Physics Today, **18**, 101 (November 1965).

less than the average preparation of biology, chemistry, and mathematics teachers in the subjects which they teach. The rate of trained replacement for this group of 17,000 is shockingly low: about 500 new persons are prepared to teach physics each year, with about half of them having a B.S. in physics; but even of that small number, about one-third is not employed as high school teachers after training, and more drop out after the first few years. It stands to reason that any course which hopes to have a realistic chance of success will not approach the subject in a revolutionary, way-out fashion, which would require special teaching skills or extensive retraining of teachers. Despite the inevitable newspaper headlines, we thus do not aspire to the label: "The New Physics".

Yet we hold that, despite the embattled state of high school physics teaching as a profession, any successfully taught course must deeply involve the teacher. It must be teacher-centered, not so much in having the teacher take class time in lecturing, but rather in the choices that the teacher will make to find a course and a role congenial to him. He must be involved in shaping his own course instead of becoming an audiovisual handyman, or merely a loudspeaker at the end of a cable. You may recall Thomas Jefferson's reply to those who were skeptical that a democratic form of government could succeed with a citizenship made of unexceptional people. Jefferson wrote, "I know no safe depository of the ultimate powers of the society but the people themselves; and if we think them not enlightened enough to exercise control with a wholesome discretion, the remedy is not to take it from them, but to inform their discretion by education".

Even if we did not have an ideological reason for giving the teacher a strong role in curriculum design, there would be simply the practical argument: we accept it as axiomatic that the most important element in the learning process is the interaction between the student and a well-trained, humane teacher. We therefore find it encouraging that in our test schools the teachers almost unanimously agree that the approach in the course allows them to teach sound physics in an exciting way, despite the incompleteness of many of its parts at this stage of development, and despite the fact that each teacher included at least one class of students of the kind that would not have been expected to sign up for the physics course as previously taught. (We have also surveyed our own students and find that a large majority responded positively to the course. Thus, to the question whether they were glad to have taken a physics course, the positive response was 79%; 70% said they would recommend taking a physics course to their friends; 63% reported they found the course challenging but not too difficult at the level of their preparation; and 83% singled out the laboratory experiments as being particularly enjoyable.)

There is another aspect of the issue of flexibility and diversity. It is essential to realize the great differences between students who are already committed to taking physics and the large group which is not so interested—and above all the fact that the former group is more homogeneous, in academic ability, in interest in science, in attitudes toward study materials, in their self expectations concerning careers. The huge diversity of the 80% who are now not taking any physics in high school is one of our main problems.

The existing schools physics courses seem not very different from one another as far as this big no-physics group is concerned. Physics seems to them to be a monolithic "thing" to be digested on its own terms, regardless of the student's individual tastes—tastes which tend, by the definition of this group, far more toward the humanistic aspects, technological ideas, sociological problems, and so forth. These students are a mixture of a great variety of atoms and molecules, with many different valences.

To some extent, so are their teachers. And indeed, if we look at the matter carefully, so are physicists themselves! All we have to do is to look around in any physics department and notice the huge diversity of interests and styles among colleagues in the same college or university department. This fact never seems to be reflected in introductory physics courses. The specialization of physicists is often bemoaned, but to some extent it is merely proof that in physics, as in most fields, there is such a wonderful variety of things to choose from, on each of which one could spend practically one's whole life. One does not have to be universal; there is a variety of scientific experience from which one can choose a specialty. Therefore, a physics course that wants to give a truthful experience to a new student must not invite the paralysis of reviewing everything that all physicists do; rather it will try to give a good idea of what some physicists have done or may be doing.

In our attempt to deal with diversity, we encounter a major new preoccupation developing in educational philosophy today: *the preservation and exploitation of indi-*

Table VII. Contents of Reader for Unit 2–Motion in the Heavens

1	The Black Cloud	Fred Hoyle
11	Into the Depths of the Universe	Helen Wright
15	Copernicus: His Aim and His Theory	Stephen Toulmin and June Goodfield
23	The Starry Messenger	Galileo
25	Kepler's Celestial Music	I. Bernard Cohen
37	The Garden of Epicurus	Anatole France
41	The Force of Gravity	Michael Faraday
51	Universal Gravitation	R. P. Feynman, R. B. Leighton, and M. Sands
55	Gravity Experiments	R. H. Dicke, P. G. Roll, and J. Weber
67	Roll Call	Isaac Asimov
75	An Appreciation of the Earth	Stephen H. Dole
81	The Great Comet of 1965	Owen Gingerich
87	The Sun and Its Energy	George Gamow
95	A Search for Life on Earth at Kilometer Resolution	Steven D. Kilston, Robert R. Drummond, and Carl Sagan
115	Space, the Unconquerable	Arthur C. Clarke
121	The Life-Story of a Star	Marshal H. Wrubel
129	A Bird's Eye View of Our Galaxy	Harlow Shapley
137	The Life-Story of a Galaxy	Margaret Burbidge
147	The Expansion of the Universe	Hermann Bondi
151	Cosmic Opera—Mister Tompkins and Cosmological Theories	George Gamow
157	Negative Mass	Banesh Hoffmann
163	The Quasar	G. Feinberg
164	Troilus and Cressida	William Shakespeare
164	Hudibras	Samuel Butler
165	My Father's Watch	John Ciardi
167	Proposition I: The Law of Areas	Isaac Newton

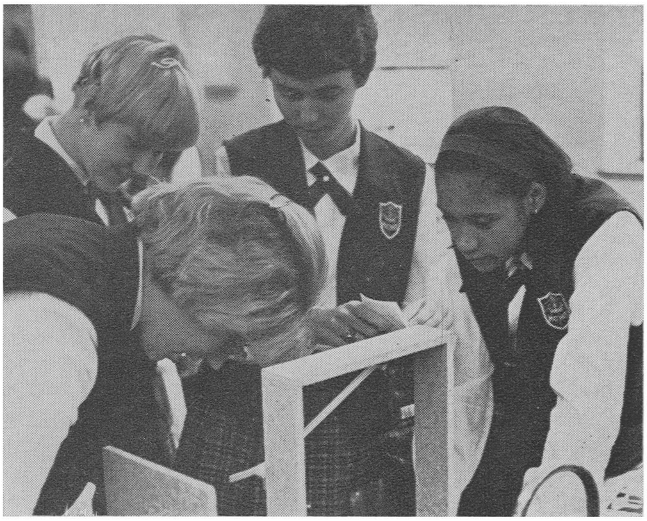
vidual differences, both in teachers and in students. To assure individual involvement, the experience of teachers and students must allow for what the individual scientists take for granted, namely, variety, options, flexibility. Once alerted, you will discover that this is indeed a strong new message which is beginning to transform educational philosophy. Thus, Patrick Suppes has recently written, "A body of evidence exists that attempts to show that children have different cognitive styles. For example, they may be either impulsive or reflective in their basic approach to learning. Indeed what we face is a fundamental question of educational philosophy: to what extent does society want to commit itself to accentuating differences in cognitive style by individualized techniques of teaching that cater to these differences?" The nineteenth-century melting-pot philosophy of education said *no* to this possibility; I believe the next few decades will say *yes*.

Already, among physicists, thoughtful people such as Walter Knight, Philip Morrison, and David Hawkins have spoken eloquently on this point. Indeed, even a century ago, Maxwell expressed it excellently, when he said, "For the sake of persons of different types, scientific truth should be presented in different forms, and should be regarded as equally scientific, whether it appears in the robust form and vivid coloring of a physical illustration, or in the tenuity and paleness of a symbolic expression". Thus, the diversity of students to whom our course addresses itself—and future physics students are by no means excluded—demands a multivalent, flexible course, with different sets of hooks for catching different kinds of attention; or, to change the metaphor, a course with different inputs and outputs to match different impedances. To take an example, in Unit 2 it should be possible for a given student to become fully fascinated with the straightforward quantitative content of the discussion of the law of universal gravitation and its consequences in physics; he should be able to pursue this by further reading [as in the *Reader* excerpts on gravity experiments (see Table VII)] and/or by doing a Cavendish experiment, or at least getting the data from film. And for this particular student this involvement might be at the expense of the study of the historical background of Newton's work, which in his case might not be of primary interest. But his neighbor, in the same class, should to some degree be allowed (and furnished equally good tools) to have somewhat the reverse experience, as long as he does not slight the minimum physics content which is set out for him in the course. When it comes to the examination at the end of Unit 2, both of these students should be able, in principle, to do exceedingly well, to demonstrate their successes. This means developing *branching* tests, and providing essay tests in addition or as an alternative to multiple-choice tests. (I have found in my discussion with the group on the College Entrance Examination Board which is responsible for writing physics tests that these ideas are by no means unacceptable at the present stage of the CEEB's long-range planning.) The conception that different students should be allowed to show a different velocity profile in going through the different aspects of the course is also quite congenial to the majority of the teachers, who would vastly prefer to see themselves as counselors, guides, and amplifiers of latent enthusiasms while they apply therapy for existing defects in each case.

The diversity of teachers being as real as that of students, we were forced to give special attention to the *Teacher's Guide*, which by no means makes the course "teacher proof". We must provide the teachers with the means, encouragement and training to take charge, to make the course their own, and ultimately to give essentially a different experience to different students in the same class, in order to lead each to an understanding of physics through his or her own individual strengths and capabilities.

Conclusion

In these pages, we have tried to indicate the large task we set ourselves, and the progress made to this point. In bringing the work to a conclusion in the remaining year, and later on during the introduction of the course into the schools, we shall continue to need help and advice from all sides. Many physicists and educators have already been heavily involved in past efforts of curriculum improvement. We can all be proud of what our profession has done for high school physics. But a great deal more remains to be done, and the burden falls on us again—there is no other group that will or can do the job. Let each of us who possibly can carry his share of the load. And even more important than that, all of us in Project Physics, and particularly the teachers who always depend on their colleagues in schools, in colleges, and in universities—all of us are banking on your continued moral support in our common goal to bring more students to a challenging study of physics.



Students working on the trajectory experiment described on page 224 in Dr. Harris's article.