Harvard Project Physics A report on its aims and current status†

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Introduction

During the last few years, about 80 physicists, teachers, film makers, experts on testing and others have been collaborating in 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. J. Rutherford and F. 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 large national curriculum project for which a need had become increasingly evident. As a result, we agreed to work on a larger scale starting in June 1964. Funds have been granted by the Carnegie Corporation, the Ford Foundation, Alfred P. Sloan Foundation, the U.S. Office of Education, the National Science Foundation and Harvard University.

An interim version of the course now exists. The materials produced were tried out in 1967–8 with over 8000 students on a controlled experimental basis in more than 100 schools throughout the United States, nearly half of which were chosen at random. After further revisions on the basis of this test we have been preparing the final version, which will be released by the publisher in 1970. From the beginning we planned on writing, testing and rewriting the materials every year during the years 1964–8, so we have been able to change our minds on quite fundamental things in the light of feedback from our classes. We have now begun to contact individuals and groups in other countries who may wish to adapt our course materials.

† This is a condensed and updated version of an article by Professor G. Holton published in *The Physics Teacher*, May 1967.

Brief survey of materials and aims

Like other major modern course revision projects, we have produced student guides, laboratory and demonstration equipment, laboratory manuals, tests, books of readings, films, loops, transparencies, programmed instruction booklets and teacher guides. This material is designed to be used in a coherent way, as expressed symbolically in figure 1, which shows one example each of the components which make up Unit 1, *Concepts of Motion*, the first of the six basic units of the course. Our course has moved away from the idea that a text must be the major source of information for the student. Many detailed discussions turned out to be much better handled through film loops, programmed instruction or the laboratory. Therefore, the burden does not remain with the printed word of the text where it has turned out to be not the best channel for learning.

If I were to select from the many objectives I would put four at the head of the list. First, we wish to create a coherent, tested course for use on a national scale alongside 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 this way, to provide variety of choice in the physics teacher's arsenal.

Second, we hope to help stem the decline in proportionate enrolment in physics at the high school level – a decline which in fact is now reaching into the college years.

Third is the obvious 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 in the United States, e.g. a single one-year course, meeting about five hours a week, in senior high school (at the age of 15, 16 or 17). Here we define good physics in the widest, most humanistic way possible rather than in pre-professional terms alone.

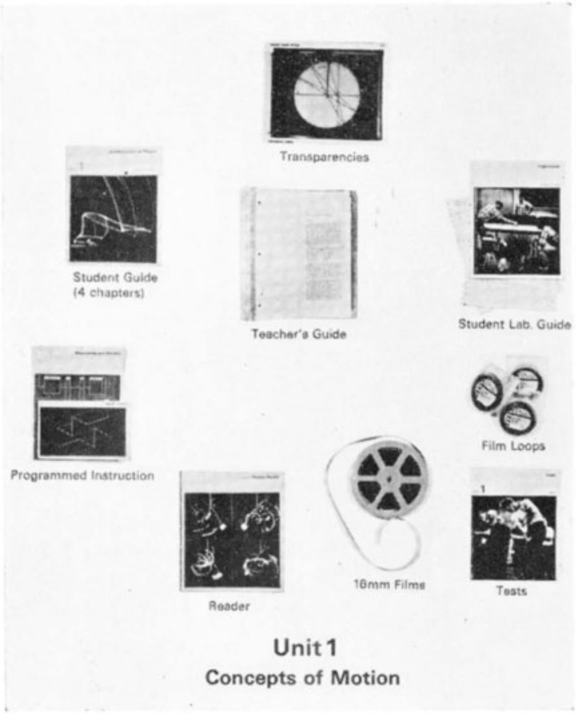

Figure 1 *Different components (media) making up a typical unit* (*Unit* 1, Concepts of Motion).

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 and abroad.

The need for new physics courses

When the National Science Foundation, in 1963, 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 electing to take any physics course has steadily declined and has now dipped to less than 20% at the last count, with only 4% of each graduating class having taken the PSSC course. This means that out of a school population of about 2½ million seniors, over 2 million each year are taking no introductory physics course of any kind in senior high school in the US. An attractive and meaningful new course might help to change this trend.

The size and variety of the intended audience define some of the problems we faced. First, every 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 a good physics course in senior high school is, in our view, also badly needed by students at the other end of the spectrum, including those who will not go to college at all.

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 in the United States, 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.

An equally important mission lies with the larger and larger numbers who go on to college to concentrate on the humanities or social studies. They also are avoiding the college physics courses and usually take at most a general college science course, with some reluctance and little benefit. 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.

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'.

The structure of physics makes it practically impossible to talk in honest detail about 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 study of the details of contemporary work.

Even a piece of older knowledge that is still recognized as good physics would, in most instances, require a major effort 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, all these are good questions. They are often asked at the oral examinations for PhD candidates. But we have preferred not to concentrate on such a catalogue of well-established items because we believe they do not let us tell a coherent story and we cannot do justice to them in the time available without continually diluting the physics.

Neither do we want to go down another road which used to be more fashionable, namely, to find those few pieces of physics which can be presented in a more or less complete and self-contained way. This was the type of physics courses in which Atwood's machine, the Wheatstone bridge, Archimedes' principle and the lens equation were triumphant. I do not think we have helped a student to really understand physics if he has studied this sort of thing, even though 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 not appreciated the general education aspect or humanistic aspect of physics: the sweeping power of a few fundamental laws, the use and limit of models and 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 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 higher vantage points and a more encompassing view of the workings of nature.

Survey of contents

We have divided the basic course material into six units, each of which is meant to occupy the average class for 25 to 40 class hours. The *Student Guide* ('text') for Unit 1, *Concepts of Motion*, 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. This material is proverbially difficult for new students and the course would be pedestrian if it only tried to drill the use of some conceptual tools such as instantaneous velocity, vectors, etc. Here we have a chance to let students learn about motion not merely by launching rockets, using an inexpensive air track

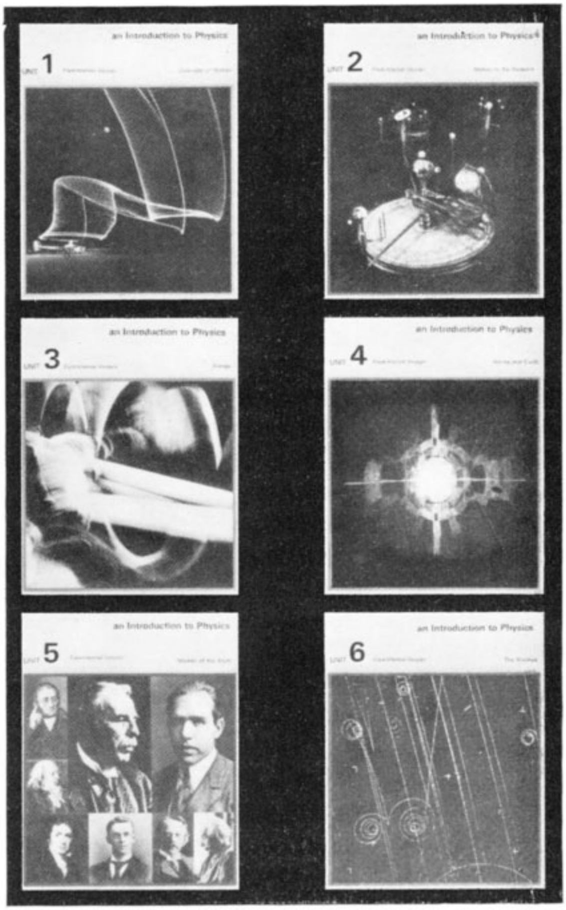

Figure 2 Student Guides (*texts*) *for the six basic units of Project Physics.*

and computing periods of lunar satellites, but also we need not pass up the chance to repeat the experiments of Galileo. 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 of stroboscopic photographs in his *Student Guide* and in the laboratory 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 pin points of light. A further abstraction then becomes possible, that of transferring the play of events to the world of mathematics. When we return to the world of real bodies, we now can master them so much better with the concepts of kinematics and dynamics.

Unit 2, *Motion in the Heavens*, deals with the dynamics of our planetary system. But in this unit we can do what in other units we have much less time for, namely, set the achievement of an understanding of the 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' Answer*; *Does the Earth Move? – The Work 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 collection of essays in the *Reader* (see table 1), the student can go beyond the scientific aspect of the Newtonian synthesis. We suggest to the student that, if he understands the way in which science influences a 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 to two-body problems to that of co-operative phenomena, a chapter on mechanical waves.

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, motion in fields, 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 simple atom; and some introduction to subsequent theories, particularly wave–particle dualism.

Unit 6 is on the nucleus: radioactivity; isotopes; the nucleus and elementary particles; and nuclear energy, not forgetting also some industrial and medical applications.

In all these units, whether in the *Student Guide*, the *Reader* or through the *Teacher's Guide*, occasions occur where the connection between physics and other sciences or other endeavours can be pointed out. Physics by itself, without ties to anything else, is a delusion which we owe to its most hostile foes and its most single-minded protagonists. To achieve anything of value in physics one may need mathematics, chemistry, metallurgy, technology and indeed the commitment of society as a whole – a point about which physicists are bound to worry 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 figure 1 and that each is meant to occupy the average class from one to two months. In addition to the six 'texts' or *Student Guides* of four chapters each, plus equipment and instructions for 50 new experiments, etc., we have produced 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 programme for those teachers who prefer to use it rather than their own.

Most teachers, certainly after their first year of use, should be able to finish the six basic units, with ample time left to add one or more *Supplemental Units.* So far we have produced two and made a start on several other *Supplemental Units* and hope for a total of about 20 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 more teacher-centred and the materials more student-matched than has sometimes been the case.

The outline given above shows that about one-third of the content of the basic units refers to basic twentieth-century concepts. This fraction can be increased to two-thirds with proper choice of *Supplemental Units*.

Principles of selection

I should say a word about the selection principles which we have been using for making decisions on the content of the course. 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 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, e.g. in scattering problems.

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. The course must be up to date by avoiding quickly obsolescent materials and 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. Bad habits we learned in our book-oriented schools must be continually guarded against and proper use must be made of other media, e.g. film loops, of which we have prepared 50 new ones so far, and short programmed instruction booklets. 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

Table 1 Contents of 'Reader' for Unit 2, Motion in the Heavens

The Black Cloud	Fred Hoyle
Into the Depths of the Universe	Helen Wright
Copernicus: His Aim and his Theory	Stephen Toulmin and June Goodfield
The Starry Messenger	Galileo
Kepler's Celestial Music	I. Bernard Cohen
The Garden of Epicurus	Anatole France
The Force of Gravity	Michael Faraday
Universal Gravitation	R. P. Feynman, R. B. Leighton and M. Sands
Gravity Experiments	R. H. Dicke, P. G. Roll and J. Weber
Roll Call	Isaac Asimov
An Appreciation of the Earth	Stephen H. Dole
The Great Comet of 1965	Owen Gingerich
The Sun and its Energy	George Gamow
A Search for Life on Earth at Kilometre Resolution	Steven D. Kilston, Robert R. Drummond and Carl Sagan
Space, the Unconquerable	Arthur C. Clarke
The Life Story of a Star	Marshal H. Wrubel
A Bird's Eye View of our Galaxy	Harlow Shapley
The Life Story of a Galaxy	Margaret Burbidge
The Expansion of the Universe	Hermann Bondi
Cosmic Opera – Mister Tompkins and Cosmological Theories	George Gamow
Negative Mass	Banesh Hoffmann
The Quasar	G. Feinberg
Troilus and Cressida	William Shakespeare
Hudibras	Samuel Butler
My Father's Watch	John Ciardi
Proposition I: The Law of Areas	Isaac Newton

Table 2 Titles of proposed Supplemental Units

Accelerators and Reactors
Special Relativity
Thermal Motion
Astronautics and 'Space' Physics
Particle Physics
Discovery in the Physical Sciences
Biophysics
Cosmology
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 Aeroplane Passenger

through the printed word, is no longer sound, either pedagogically or technologically.

A word should also be said about the place of history of science in a course such as this. Nobody in the Project has favoured 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 non-physics materials, a little goes a long way, but with our intended audience, this component is particularly important.

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. A decade has gone by since Sputnik helped spark a first round of curriculum development. Educationally speaking, this was a whole generation ago. We have today, for example, more knowledge of and different attitudes about teachers, students and schools. 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 also have changed assumptions of what is and is not feasible or desirable for schools to do.

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 a diversity of students and teachers. 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, or one that 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. He must be involved in shaping his own course instead of becoming an audio visual handyman, or merely a loudspeaker at the end of a cable. 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, 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 studied the attitudes and comprehension of our own students and find that a large majority responded positively to the course. Physics enrolment in our trial schools has risen on the average some 40% in each of the first two years. (Detailed results of all evaluation studies should be published in about a year.)

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 – above all that the former group is more homogeneous in academic ability, interest in science, attitudes towards study materials and in their 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. These students are a mixture of a great variety of atoms and molecules, with many different valences.

As far as this big 'no-physics' group can see, the existing schools physics courses seem not very different from one another. Physics seems to them to be a monolithic 'thing' to be digested on its own terms, regardless of the student's individual tastes, which tend, by the definition of this group, far more toward the humanistic aspects, technological ideas, sociological problems, and so forth.

In our attempt to deal with diversity, we encounter the problem of preservation and exploitation of individual differences, both in teachers and in students. To assure individual involvement, the experience of teachers and students must allow for variety, options and flexibility. To take an example, in Unit 2 it should be possible for a particular 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 and/or by doing Cavendish's experiment, or at least getting the data from film. For this particular student, his 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 neighbour, in the same class, should be allowed (and furnished equally as good tools) to have somewhat the reverse experience, as long as he does not slight the minimum physics content set out for him. When it comes to the examination at the end of Unit 2, each of these students should be able, in principle, to do exceedingly well in demonstrating his particular successes. This means developing branching tests and providing essay tests in addition or as an alternative to multiple-choice tests. 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 counsellors, 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 gave special attention to the *Teacher's Guide*. It does not attempt to make the course 'teacher proof'. On the contrary, we must provide 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, I have tried to indicate briefly the large task we set ourselves and the progress made to this point. In publishing the work during the remaining year, in introducing the course into schools and in helping other countries to make adaptations we shall continue to need help and advice from all sides. A great deal more remains to be done and the burden falls on our profession. 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. Even more important, all of us in Project Physics, particularly the participating teachers who always depend on their colleagues in schools and colleges, are banking on your support in our common goal to bring more students to a challenging study of physics.†

† For the *Newsletter* and other information on the Project Physics Course, write to: The Directors, Harvard Project Physics, 8 Prescott Street, Harvard University, Cambridge, Mass. 02138, U.S.A.

Why is this a bad question?

(Graduateship Examination 1963)
Why do the alkali atoms have spectra similar to the hydrogen atom?

Answer on p. 32

New films for schools

Two films for schools – *Experiment in Teaching* and *The Happy Ending* – have been made for the Department of Education and Science by World Wide Pictures Ltd, through the Central Office of Information. They are the first of a new series of DES films.

Experiment in Teaching (23 min, black and white) shows how schools are encouraging technological activities of various types; how students of different ages become absorbed in project work; and how this interest and sense of purpose results in enterprising and creative work.

The Happy Ending (20 min, colour) is a dramatized documentary about full time higher education in the technical colleges. It is designed to tell fifth and sixth formers in schools about the wide range of full time degree and diploma courses open to them outside the universities; it also seeks to encourage schools and parents to re-examine their attitudes to the colleges and their courses.

Prints (16 mm) of *Experiment in Teaching* are now available (catalogue number UK 1881) on hire and sale from:

The Central Film Library,
Government Building,
Bromyard Avenue, London W.3
The Scottish Central Film Library,
16/17 Woodside Terrace, Glasgow C.3
Central Film Library of Wales,
42 Park Place, Cardiff

Prints (16 mm) of *The Happy Ending* (UK 2646) are available on free loan (and for sale) from the Central Film Libraries of England and Wales only.