The Project Physics Course— Notes on its educational philosophy

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Science teaching at secondary level in the United States is quite different from anything in secondary schools in Britain. The most common pattern is for biology, chemistry and physics to be offered in the last three years (10th, 11th, 12th grades of high school respectively). Physics is thus an optional subject for students (the word 'pupil' has only optical connotations in the US) in their last year of secondary schooling. And most of these students will not have taken any physics before 12th grade.

Professor Holton describes the interests and abilities of the students that the Project Physics Course is intended for in this article (see for example figure 2). One must remember that there is less specialization in American schools than in British schools and that the students staying at school until 12th grade are from a wider ability band than 'traditional' British sixth formers.

The Project Physics course materials include a wide range of material: laboratory equipment, 16 mm film, 8 mm film loops, OHP transparencies, etc, as well as printed material for students and teachers.

The main course is organized into six units: (1) Concepts of motion, (2) Motion in the heavens, (3) The triumph of mechanics, (4) Light and electromagnetism, (5) Models of the atom, (6) The nucleus.

All materials (students' Text *and* Handbook, Readers, Supplemental Units, Programmed Instructions, Tests, Teachers' Resource Book *etc) are available in Europe through the agent mentioned in the footnote || on page 331.*

John Harris

In late October 1963, the United States National Science Foundation (NSF) held a meeting in Washington of some two dozen scientists and asked them to start new approaches to introductory physics teaching. The PSSC programme had been available; but in addition to the (to me, more important) argument from the wisdom of a strategy of pluralism, the scientists and officials were concerned that the proportion of students in the USA taking any introductory course in physics, alone among all the sciences, continued to decrease.

The proportion of students opting to take physics in the last years of high school in the USA had been dropping ever since 1900, as the base of students going to school was expanding. By 1960, less than 20% of the last-year students in high schools was choosing any physics course. In 1963 it seemed that this trend would continue, and indeed, by 1971 the fraction was down to 16% (Watson 1967, Barnes 1975). Moreover, between 1960–70 only about 4% (less than 100000 out of 2·5 million) of our high-school seniors per year were enrolling in the only modernized high-school course in physics then available. As figure 1 shows, during that decade there was a marked drop in the share of the students taking any physics course—from about 0·9 of the share we had in 1948–9, down to less than 0·7 in 1970.

The reasons for this pattern are by no means clear. The increasing difficulty in finding adequate scientific careers and the discontinuation of funds for teacher training in new curricula are now undoubtedly factors that add to those present in the early 1960s. Other, cultural trends may also play a role, including the rise of antirationalist or 'Dionysian' thinking (Holton and Blanpied 1975).

Beginnings of course

But to return to the 1963 meeting in Washington: Nobody there was foolhardy enough to agree to start another national programme in physics for schools and colleges, except Dr Rutherford, Dr Watson and myself. This is how Project Physics got started. The three of us had in fact begun to collaborate on writing a book; our headstart and pleasant collaboration, together with the October 1963 mandate, gave us the courage to expand our plans considerably, from doing just a text to undertaking a whole national curriculum effort. As a result, a large number of people was assembled at Harvard, starting 1 July 1964, to design, test, and remake the Project Physics Course for schools and colleges.† While the basic outline and conceptual structure of the course shows the influence of the book that caught the attention of Rutherford's class initially, one consequence of this history was that the course materials had to pass at the same time the requirements set by three people with different constituencies—a scientist, a teacher and a professor of education.

A new edition was prepared and tested out in trial classes every year between 1964–8. A total of 180

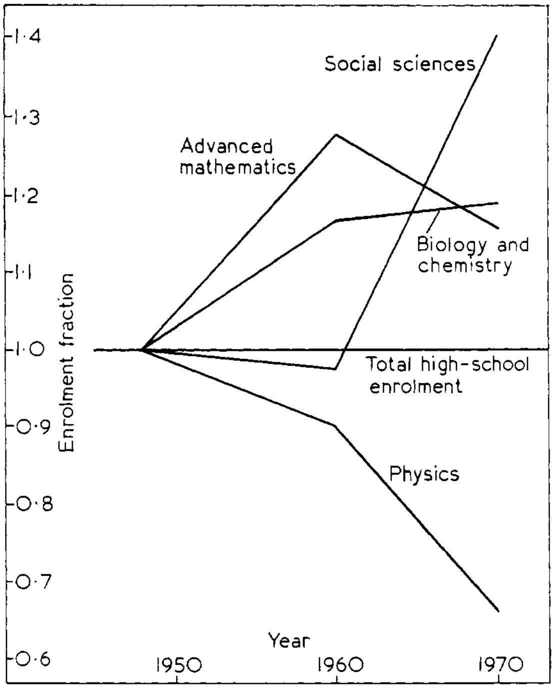

Figure 1 Fractional enrolment in certain high-school science courses relative to the fractional enrolment in those courses in 1949. Note that the drop in physics and the lower slope in biology and chemistry took place during the decade following the introduction of the new high powered curricula (*diagram and caption from National Academy of Sciences* 1973, *reproduced with permission of the National Academy of Sciences*)

professional people—physicists, college and high-school teachers, historians and philosophers of science, psychologists, reading specialists, designers, film-makers, etc—collaborated to produce the successive versions of text, anthologies (*Readers*), films, laboratory equipment, transparencies, the test programme and the rest of the course materials, distributed free to the participating trial schools.‡ In addition there were the teachers and students in trial schools, and about a dozen students who based their doctorate theses in education on the evaluation programme.§

From 1968 to 1970, the three original directors of the project reworked the whole set of materials in the light of the results of the final tests made on 20000 students. It was no simple undertaking. At last, shortly before Christmas 1970, the final version of all course components became available through Holt, Rinehart and Winston in New York and through its agencies abroad.|| What had begun in a rather casual way eight years earlier left us, as I recall, too exhausted to celebrate properly on that day. I am not confident we would have responded politely if someone had reminded us then that another revision effort, for the second edition of 1975, had to begin not long afterwards.

Current status

It is fair to say the course now flourishes. The publisher estimates that there are now about 250000 students in schools and colleges in the USA using the texts and at least substantial parts of the rest of the course materials. While it would be difficult to say whether the course was responsible for at least a levelling off of the drop of students noted up to 1971, it is a pleasant fact that thousands of teachers have undertaken to be trained in modern methods using these materials. Evidence exists for the use in an astounding range of classroom circumstances.¶

†My earlier college texts (Holton 1952 2nd edn 1973, Holton and Roller 1958) were in a sense the grandfathers of the Project Physics Course. In 1960 James Rutherford (a high-school teacher from California who had come to Harvard Graduate School) suggested that I rewrite the text at a level suitable for schools. I suggested that he write it, but the NSF failed to fund it. Professor Fletcher G Watson (at the Graduate School), James Rutherford and I subsequently joined in doing the work with a modest starter grant from the Carnegie Corporation, beginning in 1962.

The word Harvard was originally used in the title, the project headquarters being there, but between the development of the prototype course and the issuing of the publishers' version, the name Project Physics course was adopted.

‡Not all the material is essential. Some of the variety is intended to allow the teacher or student to choose; there is also material for students to select if their class is run in a way that encourages them to read on their own and do special projects.

§A booklength account of the total evaluation process and results has been prepared by F G Watson, W Welch and H Walberg. In addition some forty articles have been published in various professional journals by members of the evaluation group of the project, using the extensive test results. A list of those, and of the theses, is obtainable from Professor F G Watson, Graduate School of Education, Longfellow Hall, Harvard University, Cambridge, Massachusetts 02138, USA.

||The materials are also available through the International Office of Holt, Rinehart and Winston, 383 Madison Avenue, New York, NY 10017, USA, or, for inquiries from the UK and the Continent, preferably through Holt-Saunders, 1 St Anne's Road, Eastbourne, East Sussex BN21 3UN. Descriptive brochures and a catalogue of the course materials, as well as a newly re-instituted *Project Physics Newsletter*, are obtainable from Holt at the New York address given—for school use from the Project Physics Coordinator, Secondary School Division, and for college and university use from the Project Physics Coordinator, College Division.

¶A complete list of publications—mentioning uses or test results, successes or failures—that have come to my attention in the last few years is available from me on request.

The independent test results obtained by the Educational Testing Service (ETS) of Princeton, NJ, on how much physics these students actually learn, show that on the average our students do just as well on the ETS tests as do all students nationally in any of the new or old physics courses. So it is not to be feared that students are going to be helpless when given the unmodified national tests. On the contrary, they may well have benefited more from the alternative materials put into the course instead, not to speak of having ideally a more integrated view of what is important about physics.

One of the significant aspects of the project is the growth of many *adaptations* of the course for schools and universities around the world. From the beginning, we have insisted that we do not wish merely to 'export' slavish translations of the USA materials. We hope to provide a model both of *a style of going about making a curriculum development* (e.g. involving scientists, teachers and historians of science from the beginning, doing careful evaluation of pilot editions, etc) and of an *approach to the subject matter*. The latter—a humanistic conception of science—is really the heart of the programme, rather than any particular piece of equipment, text chapter, topic sequence, use of films or other media, and the like.

Adaptations exist or are in preparation in Australia and New Zealand, Denmark, India, Israel, Japan, Jordan and other countries. For Spanish-language and Portuguese-language countries, there are also adaptation teams at work. In Canada too we insisted on a thorough adaptation to the local cultural and educational context: Hence Canadian groups made two separate adaptations, one in French (published in Quebec) and the other in English (published in Toronto). A good deal of pure and applied science is of course entirely international; yet I see no reason why a student should be deprived of seeing the historical connections and present applications of physical science in his or her own country.

Such considerations stem from a concern which has been as important as any in designing the Project Physics Course: the influence of the materials on the total attitude of the student to science itself. Whether they will become scientists or not, it is essential that students have a chance to see the full vision of science and thereby be protected from narrow blinkers or naive euphoria just as much as from the false and hostile ideas about science and scientists which have been spreading in the last three decades, in industrialized countries particularly. The symptoms are well known.

However, it has been shown that changes are possible. Thus, on the basis of extensive educational research, Ahlgren and Walberg (1973) have published a comparison of the way different physics courses bring to the foreground of the student's consciousness the historical perspective, the philosophical perspective, the social context, the humanitarian values, the artistic aspects, and of course also the mathematical and factual base. This is a point where a chief aim of introductory physics programmes in the USA and in most other countries meet and join. Wherever knowledge and industry are hoped to be twin pillars of social strength, *the base for science is dangerously weak if the vision concerning the place and scope of science is narrow.*

In the USA, as in other countries, we must continue to try to reach a larger proportion of students than would otherwise be taking the initiative to enroll in physics courses as part of their total education. We have found that a humanistic approach to science can enlarge the pool of prospective students. Thus the proportion of young women enrolled in the Project Physics Course in the USA is nationally about twice as large as in the traditional physics course. This is an example of students who, for one reason or another, traditionally have tended to avoid the physics course where they did not have this option available to them. (We have always insisted the Project Physics Course should, whenever possible, be *one option*, not the only one. Thus we refused to take teachers into the trial programme unless they agreed to continue any PSSC sections they might already be teaching.)

Reaching a more varied audience

A problem common in most countries is how to deal effectively with those who do not necessarily have the motivation or preparation to do very well in the classical, narrowly conceived physics course. A simple but useful way of looking at this problem is given in figure 2. It represents a plane, one axis indicating the students' increasing academic ability, the other their increasing scientific interest. The plane is not populated with equal density; but we know that the student who will become a professional physicist is likely to be in the top right corner. In the USA, only about 1000 students a year become PhDs in physics, out of an age cohort of three million young people. That is a very small yield—about 0·03%. But our ideas on how to educate in physics come too often from serving that small group up there—and from having belonged to it ourselves. In fact, the fraction of the population that took any kind of physics course in US schools was concentrated there, by and large. This is the audience we do not have to struggle with too hard. The best of them will probably survive almost any method used in designing the course, although good teaching will not be wasted.

The group in the opposite quadrant, on the contrary, is one which one tends easily to dismiss. There

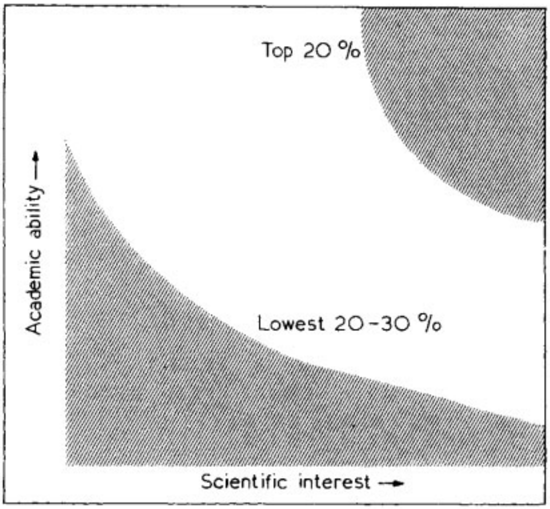

Figure 2 A 'plane' indicating the two-dimensional gradation of students by academic ability and scientific interest (*after Watson* 1967, *reproduced with permission of The American Association of Physics Teachers*)

is roughly 20–30% of each age group in it, some perhaps for temporary or spurious reasons. It is a difficult, expensive and very important area—a research subject for entirely different projects.

The rest is the 50% or so in the middle. This, together with the 20% at the top right corner, is the group of students from which we have been trying to draw our audience. This plan results in difficulties of two kinds. First, one must make a pedagogical decision, one based on a philosophy of education different from the philosophy applicable to the few percent in the top right corner, where there is a rather homogeneous group of people, intellectually and cognitively. The large majority of our intended audience presents us with a mixture of very different kinds.

Some are interested in social science, in humanities and the arts, in technology, in 'nothing yet in particular', in verbal rather than mathematical learning, etc. Some may enjoy working in the laboratory, but are poor in verbalizing and writing things down clearly. In aggregate, they are like a gas made up of molecules from the whole periodic table, whereas up there, in the top right corner, we have mainly the rare earths. Perhaps the chief trait most students will have in common across the range will be their interest in having the course make at least occasionally *explicit* what the committed prephysicist usually assumes tacitly: that science has an impact on life and thought outside the walls of the laboratory, that science is a cultural force with vast, transforming potential. (I should hasten to add that some of the most thoughtful physicists do believe that this humanist approach to science education is really just as necessary for future scientists themselves—that those in fact need the humanistic and societal elements in a science course more than anyone else, since the narrowing spirit of graduate school will descend on them all too quickly.)

But if one wishes to engage a great variety of individuals, with all their different 'chemical' properties, one must have a course which will be meaningful in a variety of ways, each of which is actually rewarded. Some students will excel in the mathematical or laboratory part, others in the more verbal reports, perhaps connected with their interest in social science or history. Hence, the assigned work, and of course the *tests*, must allow some choices or options, to permit different kinds of excellence to show up.

Updating teaching

The second, related consequence of pedagogical importance is that as instructor one should not be afraid to experiment with different styles of teaching. After all, the culture of the young and the body of doctrine in education have both moved very fast in the last decade, and we must be ready to update pedagogic ideas as we do scientific ones.

Let me cite one stimulating example. Some schools have inhomogeneous groups of 40 or more students in a single classroom. A suitable style for these was developed, called a 'modified contract method'.† The first part of the innovation was to make the whole set of course materials, including the apparatus and instructor's resource book or teacher guide (except of course the model tests and their answers) accessible to the students who are working in groups of three or four, and to make with them a 'contract' that they will take a test on the contents of one four-chapter unit at the end of a fixed period (3–6 weeks). The instructor was available as 'consultant' to each of these groups or individuals in class on demand, e.g. for short lectures. The students frequently decided to split or share the work according to individual skills and interests, for example one student being in charge of much of the mathematical work, another of the laboratory work, another taking leadership in working with the film loops or historical essays in the *Readers*.

But the reason this kind of group work was successful was the addition of one more rule: the grade each student receives after taking the unit test

†This and two of the other teaching styles often used in Project Physics classes are the subject of three of the 21 teacher briefing films obtainable from Holt, Rinehart and Winston. This particular film is called *Teaching Styles II* (listed in the Holt catalogue of Project Physics course materials as no. 084020-1).

is *the average* of all the grades obtained by the members of his own group. Thereby one breaks with the usual classroom behaviour, in which good students look out only for themselves and let the others fall by the wayside. For now they have to be teachers of the less ingenious members of their group; otherwise, in the final exmaination, those will drag down the average. In short, what happens is that by this method we introduce into the teaching process the *sanctions and rewards that are operating for research teams*, where everybody in the team shares the credit and the blame equally. In this way, the well tested and effective ethos of the research laboratory is imported into the classroom. I propose this not as *the* way Project Physics or any course should be taught, but merely as an example of changes in pedagogy that may become appropriate when we have to teach classes different from those we took in our own student days.

Content and structure

These pedagogical considerations lead us to the question of content and structure (Holton 1967, 1970). All too often, the selection principle for dealing with the unmanageable total content of physics in an introductory course is that we concentrate on fragments which are thought to be relatively easy to teach. A good deal more is included simply by habit. This is inadequate for a course that has to provide a vision of science at its best. We therefore decided to filter out whatever does not fit into the developing story line that aims to show how the basic parts of physics grew and came together. One can thereby hope to develop a sequence of organically related ideas whose pursuit takes one to an ever higher vantage point, a more encompassing view of the working nature, of the style of life of the scientist, and of the power of the human mind.

The traditional way we teach and have been taught is indicated in figure 3. One rationally reconstructed subject (kinematics) is followed by the next (dynamics, waves . . .); so one pearl after another is put together to set forth physics as it is now known, in a logical way, and rarely with more than a nod in the direction of other fields. Other instructors do the same thing in chemistry, in biology or in mathematics. The method has its uses and rewards, though chiefly for the committed specialist.

But our method had to be rather different, since we want to illustrate the way physical science actually developed as well as the humanistic and societal impact of science—those aspects which are particularly meaningful to students in the large middle group of our audience. We therefore adopt what I prefer to call a *connective approach*. Traditionally, one sees the separate academic subjects arrayed

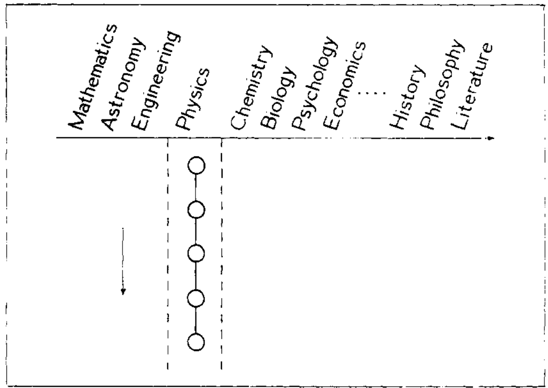

Figure 3 Traditional presentation of topics in introductory physics

next to one another—mathematics, astronomy, physics, chemistry, engineering, biology, and on to the less and less mathematical fields such as economics, political science, philosophy, theology, literature and the arts. Instructors of physics traditionally expect to attend only to a narrow vertical column of items. Yet historically, almost any of the basic findings or laws in science did develop both vertically *and* horizontally—not linearly, but as part of a constellation, an interdisciplinary network (as indicated in figure 4). This recognition allows us to present a much more meaningful story for our wider audience.

Establishing links

Thus in the first unit of the Project Physics Course we deal with kinematics and dynamics; yet there is a chance to note that the ideas of Galileo and his contemporaries were much influenced by debates (A in figure 4) that go way back in time and over into philosophy. The conceptions of the Greek philosophers certainly played great role in the fight over the very nature of physical knowledge, a fight that shaped our present ideas of science. Conversely, the success of 17th century physics had a very striking impact on later philosophy (B). For example, the conceptions of the separation into primary and secondary qualities and the mathematization of reality, which haunt philosophy to this day, started there, and are links that reach over from physics. I should stress that all such indications need to be treated in a serious (not anectodal) way, but need not be carried on to enormous lengths; of the order of 10% of class time is enough to legitimize the approach, enough to interest students and to lead them to find out more themselves by reference to existing materials.†

The next unit is on Newton's synthesis of the mechanics of the earth and of the solar system.

There we have a wonderful opportunity to show that the mathematics Newton used is to a large extent the mathematics of the Greeks (C in figure 4), and that Newton repaid this debt to mathematics by enriching the field with the development of his calculus (D). There are also links with philosophy and theology, for Newton took his ideas about space and time not out of thin air. Conversely, Voltaire was of course deeply influenced by Newton's physics, and his anitimetaphysical interpretation of it was a strong current in philosophy and theology (F). John Dalton confessed that he had found support for his ideas on atomistic chemistry (1808) in Newton's *Principia* (G), although it appears he based himself on a mistaken analogy (offering us a good occasion to demythify and correct popular notions concerning 'the scientific method').

Turning to political science, we can find explicit acknowledgment of the debt to Newtonian science and to the Newtonian approach to natural philosophy (H), e.g. in the balance-of-power imagery used in Revolutionary America. Other connections, e.g. to literature and the arts, can also be shown easily. And naturally throughout the course there are occasions for mentioning the historic links between the topics and stages of physics itself as it developed.

There are many other such examples. In our unit on energy and thermodynamics, we can and should speak of the industrial revolution and the effects of scientific advance on society. Similarly, in the unit on the nucleus we can talk about the discussions among some scientists concerning responsibility for the ethical and human values impacts of the technological aspects of their work. Undoubtedly this connects to an area of strong preoccupation concerning science among some of our students, and in any case is an obligation for a course that wishes to set science in its fuller cultural context.

Education not training

With such an approach, one ends up not with a string of pearls, all within one field, but with a tapestry of crossconnections among many fields. And that seems to me the essential task of education, in contrast to that of mere training. Training is achieved by imparting the most efficient skill for a specific purpose. Education is achieved by imparting a point of view that allows generalization and application in a wide variety of circumstances in one's later life. This difference explains why the older, linear kind of a science course, though perhaps easier to teach, is not appropriate for classes that contain students interested in the power and meaning of science, but who do not all necessarily think themselves ready to be trained as future physicists.

Teachers and scientists, being members of a group that plays a key role in the total cultural life of a nation, should be proud of the existence of this tapestry of interlinking ideas, the more so as their field, physics, has a central place in this total organic structure of intellectual history. It is altogether appropriate that they share this vision of science with their students. In the process of teaching good science, they can also convey a proper sense of the dignity of scientific work as well as of the serious civic responsibilities that are the consequences of its benefits and power.

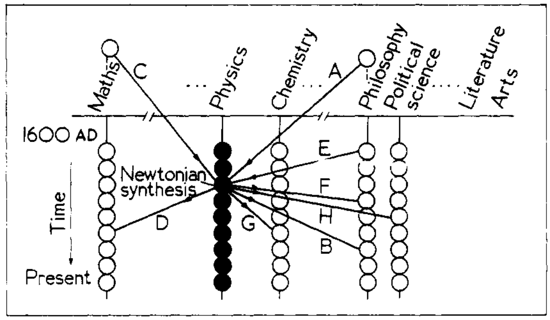

Figure 4 A specific advance in physics is linked to earlier and later achievements, not only in physics but in other fields as well (*after Holton* 1970)

†Actual articles are contained in the seven *Readers*. Annotated bibliographies are given in several 'Resource letters' (contained in the students' *Handbook*), reprinted from *Am. J. Phys.* Further bibliographies are in the instructors' *Resource Book*. An extensive bibliography of books and articles in physics, history of science, philosophy of science, etc, directed to the same sort of students, is given on pp555–70 of Holton 1973.

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