The Good Name of Science: A Discussion of Science Courses for General Education in College

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HOW CAN WE SAFEGUARD the good name of science among educated people? How can science courses in college and school give the general public a real understanding of science? The need is serious. This is a scientific age, in which the results of science affect everyday living, the thinking of scientists affects intellectual patterns, and scientists hold controlling knowledge and skill in industry, in warfare, and in matters that affect the whole policy of commerce and government. Lack of understanding between scientists and administrators brings difficulties and dangers. Administrators in businesses and in governments, even heads of governments themselves, all have to meet with scientists and formulate policies and make decisions which depend on scientific judgments; yet they find themselves ill prepared to understand the scientists' point of view or to assess their statements.

Just as serious is the problem of the general public, of the thinking man who wants to understand science, who needs to understand it if he is to play his part happily and wisely in our present civilization. Educated people emerge from school and college with little sympathy for science. Some boast shamelessly, later on, "I had a science course but I never made much of it." Science is considered abstruse and difficult or else a little crazy. Scientists are regarded as wizards with mysterious knowledge which they hand out either reluctantly or overfluently. Even high school science teaching supports this view by dazzling students with wonderful revelations and then discouraging them with powerful terminology.

Admittedly, this is too sweeping a condemnation. Yet how many of us believe that standard college courses (such as freshman physics), make the best contribution to a nonscientist's education? How many think that such courses alone give the best training to those who teach high school science to a new generation? At best such courses are interesting at the time; but their material is easily forgotten or muddled and they give little lasting benefit. At worst they produce bewilderment and dislike. Such results were sad in an earlier generation; now they are dangerous. The general student needs and deserves science courses that are an end in themselves, courses that give him an understanding of science.

In recent years, there has been growing concern for general education courses in college to provide a civilized intellectual background in an undergraduate's education. In the field of science new courses are being planned and some have started—including a few started long ago by far-seeing colleges. Scientists emerged from the war more concerned than ever over the barriers between them and laymen. The old claim that every educated man should know some science seems less important than the new one that every educated man should *understand* science well enough to work with scientists, perhaps to take something of science into his own life.

Now with general education courses being planned and tried, serious questions are being asked about them, not just by science teachers or college presidents or professional educators, but by all who have the good name of science at heart. Each reader of this paper should pause and ask himself: What do I want my children or my neighbors' children to gain from their science courses? What do I want both the future governors and the common man of the next generation to learn of or about science? Facts and laws? Or a friendly feeling towards science and scientists, and a delight in reading scientific books? Most of us, reflecting on such questions, find ourselves asking for teaching that will give genuine understanding as well as factual knowledge, perhaps at the expense of some factual knowledge—the making of new science courses for general education comes with an urgency that justifies drastic measures.

Since a number of new science courses have been started, those responsible for them are anxious to discuss aims, methods, and progress with others working on similar courses. The present article reports informally on two such conferences, one at the Princeton Inn in 1947 and one at the Lamont Library at Harvard in 1949. Both were initiated by President Conant of Harvard, Dean French of Colgate, and Dean Taylor of Princeton. The conferences themselves were small, informal gatherings—more or less accidental assemblages of people with strong interests in the new science courses.[1] They were limited to small numbers by considerations of cost and by the need for a small discussion group. This article relates mainly to the first conference, discussing the need for new science courses in college, their aims, and their construction.[2] The second conference continued the general discussions and held sessions concerned with the role of the historian of science, the relationship between the new courses and studies in social sciences, and the training of teachers. In our discussions it appeared that many standard courses in biological science are already reasonably humane, already trying to achieve the new aims. The physical scientists had guiltier consciences. So this article applies more particularly to the physical sciences.

Orthodox Courses and New Courses

In many colleges, the only science courses available for nonscientists are orthodox courses in single sciences, originally designed to provide a sound foundation for further courses in the same science. Nonscientists take these courses, under university rules enforcing broad general programs or through their own interests and choice. The emphasis in these courses is mainly on content rather than on ideas or scientific method, and there is not enough time to give thorough understanding. Their use for general education has been defended on the grounds that a thorough learning of facts and principles does give an understanding of science; that the discipline of hard study is good in itself; and that routine work in classroom and laboratory gives training in scientific method which will spread to other studies and other activities in the student's life, making him more scientific.

When we judge such courses by their practice we find them crowded with material, particularly in the physical sciences; and when we judge them by their results we find they do not turn out many general students with a sympathetic understanding of science. So we turn to planning new courses with two special characteristics: (1) they are ends in themselves, intended for students who will study no more science, except in their own reading in later life; (2) they aim at producing sympathetic nonscientists who understand something of the nature of science, who feel they know what scientific work is like and what scientists are like, who have seen experiment and theory and critical argument used in building a structure of knowledge.

Transfer of Training

Our psychologist colleagues, however, give educators a serious warning about hopes that training given to a student in a science course will spread to other activities—hopes that one intellectual activity can sharpen the mind, or improve its ability for some other activity. Just such hopes have been used to defend the discipline of an orthodox course. And just such hopes lure all of us into planning to do great things with new courses, such as make people more scientific. Before we condemn orthodox courses or plan new ones, we need an answer to this key question: Will students transfer training, in some skill or habit or the use of some idea, from a science course to other studies or to life in general? If the answer is *no,* our new schemes offer little promise as part of general education. If the answer is *yes* our hopes should be grand.

In the past, educators placed great value on courses in classics, history, mathematics—in fact, on most of higher education—because they took it for granted that training in one field would transfer to many other fields and be retained as part of the student's general culture. Classics, it was claimed, trained students' minds and made them develop into scholars. In this respect, educators seem to have risked some confusion between *post hoc* and *propter hoc*—we might suspect the classical scholars had the intellect to succeed anyway. Since early this century there have been doubts about the hoped-for transfer. At first, experimental investigations said *no* to our key question; then later studies showed that transfer can occur to some extent. It certainly does not take place as easily as educators and the general public hoped. As one example, consider scientists themselves: are they better for their studies, tidy and systematic in their general life, critical and unbiased in their general thinking?

If transfer does not occur at all, higher education seems almost worthless, except for specialized professional training. Fortunately there is some transfer—language teaching can improve intellectual skills,

[1] The conferences were peculiar in the one-sidedness of their personnel. Practically everyone there was already in favor of the new courses. It was like a bench of bishops meeting to discuss some general issue—perhaps it would be fairer to say a meeting of ministers of many faiths gathered to consider some common project. With this select clientele there was plenty of discussion but little straining of argument across major differences of ideals. The speed with which we could clarify our ideas and discuss methods was amazing. As a form of conference to help progress, this kind of gathering deserves strong recommendation; and I hope that conferences constructed similarly will be sponsored in many parts of the educational field. Professional societies and universities might find this difficult—the limited invitation would seem undemocratic—but here is a magnificent chance for foundations, which can issue a limited number of invitations to people who will come ready for profitable discussion.

[2] Accounts of some of the courses discussed have been published in *Science in general education,* edited by Earl J. McGrath (Wm. C. Brown and Company, Dubuque, Iowa, 1948).

mathematics can give a sense of form or provide training in careful argument, and so on—but *only under certain favorable circumstances.* These favorable circumstances[3] seem to be:

I. The more there is in common between the field of training and the field to which we wish it to transfer, the greater the likelihood of transfer. There need to be common elements, which may be elements of material or method or ideals. For example, if we train a student to weigh accurately in a physics laboratory, it is almost certain that this training will transfer to another physics laboratory and he will weigh the more accurately there; it is moderately certain that he will carry his good training to a chemistry laboratory; much less likely that he will carry it to any weighing he does in his own kitchen or in his business; and it is very unlikely that the training in accuracy will reappear as a habit of being accurate in other activities. Another example: training in argument learned in geometry is likely to be transferred to later geometrical studies, not very likely to be transferred to work in physics, unlikely to help the student to think critically about arguments in newspaper advertisements, and very unlikely to make him a better economist. (We can modify the gloomy doubts expressed in these examples by attending to conditions II and III.)

II. Consciously seeking transfer may help transfer. We should encourage the student to review his gains in the field of study; then we should point out their applicability to other fields. We should even urge him to look for chances of transfer and remind him that unless he transfers some of his gains to his general life, our course will be of little lasting value. (We ask the student an intellectual version of the question that is put to a child: "Now Johnny, if I *give* you a tennis racket, will you *use* it?")

III. An almost essential lubricant for transfer is emotional attachment—the extent to which the student associates feelings of enjoyment, interest, and inspiration with his studies. The more he enjoys his science and is inspired by its skills and methods, the more he likes discussing its philosophy, the more likely he is to retain and transfer it. Thus, to return to our examples, a student who develops a delight in accurate weighing, making accuracy almost a minor ideal, may well carry the techniques and attitude of seeking accuracy far and wide in his activities, particularly if he has been made aware of the possibility and value of this wide transfer. The student who develops skill in geometrical argument and feels inspired by the method may well become the clearer lawyer or cleverer economist by the transfer of some of that training.

IV. It has been suggested that ease and amount of transfer increase with increasing general intelligence. This seems reasonable in the light of the other requirements. If this is true, the brightest students should profit most from courses in general education.

We now return with gravely increased doubts to the orthodox science course, in which the student is carried through topic after topic, learning things for examination purposes, without much time to consider or discuss or even to think about the nature of science. He does not develop an ideal of being scientific. The discipline of a physics course crammed with facts and principles, derivations and problems, may teach him physics but it offers poor hopes of transfer. So those of us who want to give students an appreciation of science, as well as some knowledge of it, seek courses in which we cover less material and have more time for other uses in the course. If students are to learn about scientific method they will need more time to study the harder parts of the content carefully so that they understand what they learn—a headache over difficult material treated too fast would be a poor basis for transfer. There must be time for student discussion, for careful reading and clear teaching, for historical analysis, for arguments and for expositions of the nature of science; above all time for students to turn around often and look back on the way they have traveled, trying to understand what it is all about instead of merely knowing facts or rules soon to be forgotten.

The New Courses

Realistic Aims. Turning the comments on transfer towards our aims for new courses, we again meet doubts. We doubt if we can cultivate general abilities or "train the mind." We doubt if we can give a complete conspectus of the basic principles of the physical and biological world, their implications for human welfare, and their influence on the development of thought and institutions, except a short-lived one that fades after the examination. We doubt if we can train critical thinkers—at best we can encourage critical thinking and hope for some transfer, if we plan for it. We are even doubtful about training

[3] A useful 8-page report on this matter was published in 1930–31 by the British Association for the Advancement of Science. In that "Report on Formal Training" Prof. Cyril Burt wrote:

A common element is more likely to be usable if the learner becomes clearly conscious of its nature and of its general applicability; active or deliberate transfer is far more effective and frequent than passive, automatic or unintentional transfer. This seems especially true when the common element is an element of method rather than of material, an ideal rather than a piece of information.

And Prof. F. A. Cavenagh wrote:

It thus appears that this transfer exists, and that it can cut both ways. If education consists in "what remains after we have forgotten all we learnt" it may be no more than a dislike and contempt for any serious mental pursuit, for anything "high-brow." On the other hand, it may mean activity of mind and the capacity for finding interest in any task, and for constantly increasing the circle of one's interests.

students in scientific method with serious hopes of transfer; this seems to be asking too much. However, by leading them through a variety of scientific methods we may give them an appreciation of science which will transfer. Aims such as making students understand what science is like, and what scientists are like,[4] are more realizable, we believe, and many of us would be well satisfied with moderate success in these alone. Thinking of transfer from classroom to later life, we are tempted to transpose the word *like* in these aims and say, "to make students like science, and like scientists." If they do not enjoy their acquaintance, it is likely to be a brief one.

Content. The new courses should mediate between the layman and the scientist, between a classical culture and a scientific civilization. They cannot do this just by pouring in scientific information or formal training. They must try to give a sympathetic understanding of science and the way scientific work is done. To make this understanding a lasting part of people's culture is a huge task. In a one-year course we can give only glimpses of it; and to do so will mean omitting at least half the orthodox course content.

We need have no fear that the new courses will lose all content and become easy talks about science. To achieve our aims we must deal with solid scientific material. Though we remove half the topics of an orthodox course, students may learn more rather than less in studying the rest more carefully, and may remember more material some time after the course. We can choose the material we keep and tie it together in such a way that they really have a chance to learn what science is like—and to like it. With an understanding of the nature of science they should be able to look up facts in books and they are likely to retain a lifelong interest in scientific reading.

The Block-and-Gap Scheme

In the conferences, we found a common element in all our schemes for new courses: the reduction of content to a smaller number of topics which are to be treated carefully as samples of scientific work.

To make discussion of schemes easier, I suggest the descriptions and names shown in Fig. 1 for various types of science courses. Let us represent the field of scientific knowledge by a table ABCDD′C′B′A′, containing a vertical column for each science. (For example BCC′B′ represents physics. I shall use physics as my example but another science would do just as well.)

The orthodox courses, labeled alpha and beta, proceed straight down a column, covering subject matter as thoroughly as time and the students' preparation

[4] In their work and in its effect on other people, not in their personal lives.

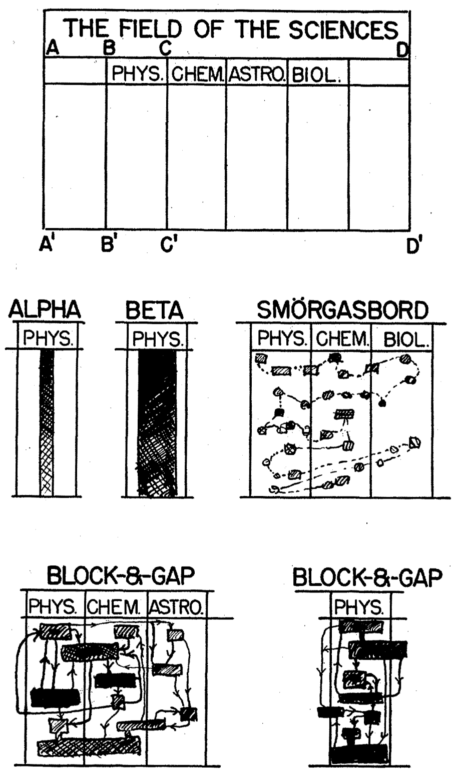

Fig. 1. Subject matter in science courses.

permit, usually trying to lay a foundation for later courses. Some colleges offer several such courses for students with different preparation or interests. Of these, beta is a standard freshman course. All the important topics are treated in turn, often with little time to show their consequences or their interrelations. History may be mentioned but it is not discussed and certainly not brought to life. Beta is well packed with content. (In physics courses of this kind, problem-solving involves many arithmetical substitutions but contains some algebraic argument and derivations.)

Alpha is a "thin" or easy course which begins at the beginning and mentions topics thoroughly but avoids the hard parts of the treatment. (In physics, such courses are often recommended for students who have not studied physics before, and they are sought by many premedical students. They seem hard enough to their customers, but to their instructors they often seem too easy and too dull. In tests, easy numerical problems are more common than derivations involving argument. The student's real understanding is not inquired into.)

To meet the needs of general education, some have suggested and tried a survey course running all over the field of several sciences, mentioning as many topics as it can. Some people believe this kind of course gives the student valuable acquaintance with the sciences. Most of us condemn it as giving a useless smattering of facts with no time for discussion or real understanding. We can draw a tenuous line connecting the topics, but such continuity has little educational value. I have labeled this the "smörgåsbord course." (The title "survey course" is easily misunderstood.) It is doubtful if this wild rush through many topics meets the needs of general education. Besides being too superficial, it makes science seem a glamorous wonderland of facts and names, announced by the wizard-scientist—a damaging piece of negative teaching.

Putting into a diagram our prescription of less subject matter treated more carefully, I have sketched a scheme which I call a block-and-gap course. The blocks represent the chosen topics. They are taught thoroughly (so that the blocks are *dense*) and their background is explored (so that the blocks are *extensive*). Connecting the blocks are discussion lines along which flows the lifeblood of the course: historical studies, arguments about experiment and theory, ideas and information carried from one block to another, and thence, enriched, to still another or back to the first one—showing the organic structure of science. The gaps are essential; they reduce the content of the course so that there is time for discussion, time to see interrelationships, time for ideas to sink in, and time for the student to look back and reconsider.

Blocks may be chosen from a single science or from several sciences. In working practice, these two kinds of block-and-gap course do not differ greatly. There are those who insist that the methods of the different sciences differ so greatly that we should take samples from all sciences. But in a one-year course we might lose more by such diversity than we gained.

The block-and-gap scheme is a mere artifice to express general policy. It does not say what blocks should be chosen, nor does it show how they should be treated. Each group of teachers should choose its own set of blocks—the conscious effort involved contributes to the health of the course. Those starting a course would be unwise to copy someone else's choice; very unwise to choose too many blocks and thus return to a beta course.

Treatment of Blocks

At the conferences we seemed agreed on the restriction of content to a few blocks, on the insistence that the blocks be treated thoroughly—more thoroughly than in a beta course—and on the importance of discussions, relating the blocks and commenting on them. But over the great question of how the blocks should be treated there was no general agreement. Probably, if we keep our attention fixed on our newly emphasized aims, we may use any treatment that fits the interests of staff and students. The history of the growth of a piece of science makes the science itself seem clearer. So we expect historical treatment to be useful. To some students, scientific work remains unreal unless they try it themselves; so we find laboratory work advocated—without the deadening effect of cookbook instructions. Ordinary teaching methods, such as expounding material and arguments in lectures, can be directed towards our new aims; so we meet pleas for saving time and money by lectures. Here is a list of some of the methods being tried:

Case histories. This is the method suggested by President Conant in his book *On understanding science.* In the hands of well-informed, enthusiastic teachers, this makes a marvelous course for certain kinds of students. Cases from many sciences can be selected, giving a much fairer account of scientific work and thinking than selections from a single science. Many of us believe that students emerge from such a course with a real appreciation and understanding of science. This course uses original writings and accounts of research by great scientists, very fully edited for students and accompanied by notes and reading from ordinary texts. Help is needed from professional historians of science, for editing material and for arranging the course, and it is to be hoped that colleges will establish faculty posts in the history of science for this purpose.

Study of original documents. This is a more extreme method, which encourages students to read original scientific writings very critically. Like the method just described, it needs good translations and reprints, many of them not yet available. Used alone, it is a slow method and probably should be combined with other methods, such as laboratory work.

Courses in the history of science by qualified historians. Excellent in themselves, such courses probably deserve to be preceded by a course in science and are better given in a special department. Conference members doubted that such courses would meet their aims for the general student, but felt they were almost essential in the preparation of future science teachers.

Orthodox presentation. This method makes use of lectures and laboratory work, etc., in the orthodox way, but with a new spirit. It is speedy and clear but lacks a certain needed flavor of genuineness unless combined with some historical treatment. Laboratory work is thought by many to be essential but it is costly and requires instructors who will be patient and silent and refrain from urging students to "get the right answer." The business of the laboratory is to give students close contact with scientific work, to make them aware of its difficulties, as well as its delights.

The same sense of reality may come from careful study of case histories, so in that course laboratory may be unnecessary—the laboratories of great scientists are brought into the students' library.

Teachers

What teachers are needed for such courses? Ideally we need a group trained in several sciences and in the history of science and in philosophy, people with special interests, perhaps with special teaching skills. Actually we find we can do well enough with a group of teachers picked from the usual science faculty, picked for their sympathetic interest in such courses. With the will to make the course succeed, young teachers learn in a few months to run classes and laboratories. Frequent staff conferences are needed, but then the discussions are far more interesting than routine-staff meetings of a beta or alpha course. Out of the new courses themselves will come teachers for the next generation of new courses. For these new teachers we can advocate training in the history of science and in philosophy as well as orthodox subject matter in several sciences.

Integrity

However the blocks and gaps are treated, we need all through the course a certain quality of intentness and relevancy. We need to be intent on the future of the course and on the past. Each block, reasonably complete in itself, must fit with other blocks, both use them and be useful to them in showing the structure of science. We should be intent on showing the growth of science from empirical knowledge extracted inductively to knowledge built into a structure of theory tested by experiment. We should make sure that reading and laboratory work and examination questions are relevant, above all in their attitude. We must aim directly at our goals, so that students can see and appreciate them.

Consider the teaching of scientific method as an example. Simply listing "method" in our program does not assure success. Routine drill in scientific procedure will do little good. Preaching at students a unique scientific method (devised by Francis Bacon) gives a stultified picture of scientific procedure which they may rightly reject as unreal. We should do better to have them find that science uses a variety of apparatus and techniques and then see that a problem can be investigated from several points of view—thus finding, in these senses, many scientific methods. Finally we may be able to show there is a single underlying method: the way in which scientists build up a sense of assurance or validity about scientific results as they proceed from empirical knowledge towards established theory. If we aim intently at these stages of understanding we may carry students with us.

I call this essential quality of intentness and relevance *integrity,* (with a slight flavor of integration). Each item in the course must be true to itself and true to the rest of the course and its aims. Without integrity, a block-and-gap course, run carelessly with a patchy mixture of topics, will be a failure—a tepid cafeteria meal. With integrity, we believe the new courses can do great things and are already succeeding in some measure, so that their students *will* maintain the good name of science.