While the national income has tripled, the author points out, expenditures for public education have remained practically static. Factory wages have gone up an average of 56 percent while salaries for teachers have advanced only 7 percent. Since most extra earnings of factory workers were made possible by increased output resulting from use of machines invented and designed by scientists and engineers trained by teachers, he adds, we have here a flourishing vine that doesn't know yet that its roots are withering.

THE ROLE OF TH[E] IN THE TEACHIN[G]

By ***George R. Harrison***

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SECONDARY SCHOOL OF SCIENCE

A SERIOUS SHORTAGE of scientists and engineers exists in the United States at the present time, which appears likely to become very critical in the next few years. It is evident that only part of the shortage arises from the present emergency, in which the scientist becomes for the first time one of the most important factors in military planning; long-term shortages of scientists also exist which are likely to affect adversely the national economy and morale. From industry, from government laboratories, from universities, from the teaching profession itself, comes increasing clamor regarding the shortage of scientists in both fundamental and applied fields.

Each technological field tends to follow a sigmoid growth curve, starting slowly, then rising faster until it approaches a fairly constant maximum slope on a logarithmic basis, and ultimately entering a saturation and levelling-off period. By plotting the course of the curve from the beginnings of a given field to date we can get a fairly good idea of its future course, and an indication of whether a field is relatively youthful or approaching saturation. Thus the number of students in public secondary schools more than doubled every ten years between 1890 and 1930, but then the enrollment became more than half the age group, and obviously could not double again.[1] The three sciences of most importance in our discussion, chemistry, physics, and biology, have given rise to technological fields which are respectively examples of young adult, adolescent, and infantile fields. Since potential engineers are almost indistinguishable educationally from potential scientists until well into college, I shall in this paper include engineers also as a category under the heading scientists, and compare the availability of and need for scientists in these four categories.

Of the total working population of the United States, about one person in 100 is a scientist in the technical sense. Of the 600,000 in this category, two thirds are engineers and one third practitioners of the natural sciences. The number of engineers, now about 400,000, has been doubling every twenty years. The number of chemists, now 100,000, doubles every fifteen years. The total number of natural scientists, 200,000, doubles every ten years. The number of physicists, less than 20,000, doubles every eight years. The rate of growth of the number of biologists, of whom there are now about 30,000, is difficult to assess, since most go into fields not related to industrial biology. The shapes of the appropriate growth curves indicate that engineering is rather mature in its development, though there is as yet no indication of any approach of a levelling-off period. Chemistry, which started growing rapidly between the two world wars, appears now to be in a period of fairly stable growth, and can be thought of, in terms of the national economy, as a young but adult science. Physics, on the other hand, entered its period of rapid growth as a result of the developments made during World War II, and is only now emerging from adolescence. Biology is far down on the starting portion of its growth curve, and in terms of national utilization of biologists in industry and government must be considered a pre-adolescent just getting ready to flourish.

Entirely apart from needs arising from the emergency, American industry now requires from 20,000 to 40,000 new engineers a year. About 25,000 will be created this year, but the falling-off of enrollments in engineering curricula indicates that we will reach a low point of about 15,000 per year five years from now, and that much more serious shortages of engineers than the present one can be expected in the next decade. Yet some high-school guidance counsellors still advise their students that there is a glut of engineers.

The chemical industries have grown fourfold in economic importance over the past twelve years, yet the number of chemists and chemical engineers has not even doubled during that period. About half of all chemists are employed in research and development jobs, so that their importance in the chemical industry, which is rapidly approaching the steel industry and exceeds the automotive industry in magnitude and national importance, far transcends that of the ordinary productive worker. This situation is additionally complicated by the fact that the government has increased its employment of professional chemists over the past decade from 15 percent of the total number to nearly one third.

Lux and Moody[2] estimate that in 1954 and 1955 there may well be an accumulated shortage of chemical engineers alone of between 15,000 and 25,000, over one fourth of the number needed by that time in industry. In the fall of 1950 there was a decrease of 20 percent in undergraduate engineering enrollments, compared with a general decrease of 6.5 percent in overall undergraduate enrollments, relative to the previous year. In fact, a smaller percentage of the high-school graduates of 1950 entered engineering than was the case prior to World War II.[3]

AS TO PHYSICS, the present tremendous demand for physicists might be thought to arise from the wartime developments in nuclear energy and electronics, but this is only partly true. Actually such classical fields as optics and acoustics are building up even greater pressures for physicists than are the newer fields. To some extent this is due to defections of employees to the new fields; nevertheless the number of trained workers in acoustics and optics is doubling every eight years, at the same rate as for physics as a whole. Still greater demands for trained physicists can be expected in the future than in the past because many newer branches of engineering, such as those involving phosphors, semiconductors, photoconductive materials, etc., are based on quantum physics, which must be added to the classical physics on which present fields of engineering largely depend.

Despite these facts, emphasis on physics in secondary schools is apparently declining, and there is an increasing tendency to substitute as a science requirement descriptive courses in general science or hygiene. This is of only secondary importance; the really dangerous factor lies in the diminishing relative importance of the sciences in the thinking of the secondary-school student.

In March of 1951 the Bureau of Labor Statistics estimated that from 70,000 to 105,000 first-year college students are needed each year to enroll in scientific curricula, including engineering. Thus the 25,000 secondary schools should be turning out about 100,000 graduates a year oriented toward science. They actually turn out less than half this number. Out of a total of about 1,600,000 secondary-school graduates per year, 300,000 or some 20 percent enter colleges, but of these not more than one out of five or six makes science or mathematics a career. Allowing for 50 percent depreciation in college, we see that not more than one high-school graduate out of fifty becomes a scientist or mathematician of any sort. Why is this?

One immediate reason is that only about 6 percent of secondary-school teachers teach science, and of this number many are not trained as science teachers.[4] Another is the plentiful job situation at high pay for high-school graduates, so that many who might go into science and engineering take immediate jobs in industry. The most common scapegoat is the poor old Bureau of Labor Statistics, which had the misfortune to announce some years ago that the engineering field was becoming overcrowded. Some high-school teachers undoubtedly are still affected by this pronouncement in their counselling of students, but I am inclined to agree with Fletcher Watson of Harvard, who feels that the present lack of science candidates is mainly the result of having the good science teachers in the secondary schools drawn away from teaching during the war years, so that the pupils in these schools did not come in contract with teachers who were really interested in their subjects, but were taught science by teachers whose main interests lay in other fields. Unfortunately there appear also to be long-term trends in this direction which bear little relation to the emergency.

In summarizing manpower shortages in science we have, of course, been talking principally about products of four-year college courses, which compose the great majority. Yet of even greater importance in the national picture are the products of six and seven-year college professional curricula: the engineers, and the doctors of science and philosophy in scientific departments. Here the shortages are even more marked. In chemistry we produce only about a thousand doctors a year, or 10 percent of the total number of new chemists; in physics, 400, or about the same proportion; in biology only a hundred, or around 1 percent. (This last figure, which doubtless reflects college biology curricula as a preparation for medicine, forestry, and agriculture, shows the very small production as yet of truly professional biologists.[5]) Yet the proportion of scientists with advanced training is increasing.

Of the 200,000 American scientists exclusive of engineers, one sixth or 33,000 have doctorates, and this number is increasing at about 12 percent per year. This number will doubtless continue to increase relative to those graduating each year from high school.

As a microcosmic indication of these changes it is of interest to examine the output of the Massachusetts Institute of Technology, a university of carefully selected objectives whose overall growth in enrollment has been held down to slightly more than 50 percent in the past decade. During that period, in which the postgraduate enrollment more than doubled, the enrollment for graduate study in biology remained constant, that in chemistry nearly doubled, while that in physics almost quadrupled. The microcosm does not entirely reflect the macrocosm, however, for during some of this period MIT was furnishing more than 10 percent of all the physics doctorates of the country. The figures are of interest mainly as showing a relative shift from engineering into science, corresponding to the national picture, and the effect of the different parts of their growth curves on which biology, chemistry, and physics now find themselves.

The statistics quoted have been directed toward showing that insufficient numbers of students enter science as a career under the *normal* development of American industry and education. Now the problem is compounded by the emergency, when scientists and engineers are in demand as never before. Graduates of science departments are coming to feel hurt if they do not have a choice among at least six jobs, and the salaries offered incipient PhD's exceed those earned until recently by men of similar ability and training after ten years of experience. The situation in scientific and engineering placement reminds me of the hunting situation in Maine, where one hunter is shot for every 1500 deer. In the bitter battle for science graduates one company recently sent out 22 of its engineers to conduct interviews, but only 21 came home—the other had been hired by a rival. At a recent joint meeting of the professional societies of American physicists in Chicago the number of personnel officers with desks in the placement bureau almost equalled the number of candidates for positions, and most of these latter were merely candidates for possible *other* positions.

In the words of Charles A. Thomas, Chairman of the Scientific Manpower Advisory Committee of the National Security Resources Board: "We need physicists, we need chemists, we need biologists, we need engineers—there are not enough men in any of the categories." For the long pull we must depend on the secondary schools to select and prepare additional potential scientists and guide them into the paths of scientific education.

It is apparent that we are entering a period in American industry when the competition for that percentage of the population which is capable of being educated for more than twelve years with advantage to the nation and to themselves is becoming keen. Our population has grown 60 percent since 1900; the numbers specializing in science and engineering have grown 700 percent, but during the same period the number specializing in modern languages has grown 800 percent. Eventually we shall be educating for nineteen years, i.e., to the doctorate, everyone who can benefit from such an education. There is some evidence that the number who can benefit from sixteen years of education is now less than twice the number entering our four-year colleges and universities, but the fraction going on to the doctorate is still so small that it can be increased effectively many-fold. In the high school, however, we are now enrolling 80 percent of all eligibles in the age stream, whereas in 1890 only 7 percent of all eligible youths attended high school, and even today no European country has exceeded 15 per cent. This is the great phenomenon that is likely to be forgotten when our college students are compared adversely with those of European colleges; the fraction of our population that goes to college approaches 20 percent, whereas in Europe it seldom exceeds 2 percent.

ONE NEED NOT SEARCH FAR to collect a vast assemblage of critical comment on secondary-school education. One hears a teacher of freshmen college physics wishing his students had had no high-school physics, since "they have so much to unlearn." One hears the world-famous head of the biology department of an outstanding university, whose students place near the top in passing admission examinations for medical schools, announcing that he had flunked his daughter's examination in high-school biology, which, consisting of outmoded details of taxonomy, had in his opinion no connection whatever with modern biology. One sees a freshman floundering helplessly before the card catalog of the university library because, having graduated from a "progressive" school, he has never learned the alphabet. One reads, as in an article by Harry J. Fuller in the *Scientific Monthly* for January, 1951, "There is a marked deterioration in the contemporary training of students, particularly in the high school. College professors are generally aware of this deterioration, which has been rapidly accelerating during the past fifteen years."

Quite obviously secondary-school education, and especially education in science, is going rapidly to the dogs. Yet if we examine the record we find that this has always been so, and we see the remarkable phenomenon that high-school education, getting progressively worse since the beginning, is now probably at its maximum effectiveness to date. The answer to this paradox lies in a study of distribution. Our secondary schools now turn out larger numbers of better educated students than ever before in history. They also turn out large numbers of students with glaring deficiencies in basic learning.

An interesting example of opposing points of view regarding secondary-school teaching appeared in the pages of the *Scientific Monthly*, where in January, 1951, Harry J. Fuller, a botanist at the University of Illinois, assembled the criticisms of modern pedagogical formalism, and amid the joyful whoops of his fellow-scientists presented a boldly overdrawn and caricatured picture which lays the Schools of Education out cold. He also dramatizes with overstatement many of the things we feel to be true regarding the deficiencies of modern secondary-school education. Thus he says, "According to the high priests of pedagogy, failing a high-school student in his courses or refusing to graduate him if he does not achieve a creditable proficiency in his studies may engender in him profound and prominent psychological aberrations which will doubtless lead him into a life of crime, a career as a scribbler of obscenities on washroom walls, or a sticker of thumbtacks into his mother-in-law."

The rebuttal to these arguments is well handled by Simon Williams and James T. Laurits in the *Scientific Monthly* for May, 1951. They point out that the so-called degeneration of the lower schools, blamed on progressive methods, can be ascribed to simple statistics, and that whereas Terman estimates that an IQ of 110 is needed for success in traditional classical high-school curricula, 60 percent of all American youth rank below this level. With increased social pressures building up high-school enrollments, we are obviously approaching a saturation point, and if more high-quality scientists are to be produced they must be found by improved selectivity, as well as being produced by better training.

In my opinion, while Williams and Laurits have effectively shunted much of the obloquy from Schools of Education which Fuller has heaped on them, they have answered most of his criticisms but not all. The great contributions of the progressive movement have been first, the cracking of the shell of a calcified educational tradition, and second, the realization and demonstration of the importance of motivation. That it swung too far cannot, I believe, be denied, and one of our present tasks in education is to redress the proper balance. In the meantime the numbers of incipient adults who can neither read nor spell, and have never been forced to stand up to any difficult problem or submit to any natural discipline, present a real problem.

A great danger in secondary-school education is the growth of superficiality. Under the guise of modernity high-school science teachers embark enthusiastically on programs regarding atomic energy, for example, who have almost no understanding of the laws governing energy in general, and cannot solve a problem in simple friction. While this sort of thing may be justified as helping to motivate students toward science, it is likely to motivate the wrong people. Here we need to mention mathematics as an important secondary-school subject, for courses in mathematics are of the greatest importance as being both selective and disciplinary. Mathematics is one of the few science courses that is difficult to teach in a descriptive rather than a rigorous manner.

There is too great a tendency for the secondary schools to ape the colleges. This is natural, since their original purpose was almost entirely to prepare students for college training. The colleges tend to encourage this, since from their standpoint the secondary schools exist to train students for them. From the standpoint of the secondary schools, more than three fourths of their pedagogical effort must be dedicated toward the education of future citizens who will never obtain further formalized education. The colleges should not be blaming them, but should be helping them in the selection and differentiation processes. One way the colleges could help would be by eliminating many of the detailed entrance requirements and insisting instead on certain standards of intellectual excellence and mental discipline. Great strides have been made in this direction as a result of the testing and examination programs now current, but the colleges are still much too specific about what items of information their prospective students must have learned.

AS TO SECONDARY-SCHOOL TEACHERS, it does not take an eagle eye to see that they are more to be pitied than censured. While the national income has tripled, expenditures for public education have remained practically static. While factory wages have gone up an average of 56 percent, teachers' salaries have gone up an average of 7 percent. Since most of the extra earnings of the factory workers were made possible by increased output resulting from use of machines invented and designed by the scientists and engineers trained by the teachers, we have here a flourishing green vine that doesn't know yet that its roots are withering. Unfortunately this problem is very difficult to attack because the income of the laborer is principally a matter of dynamic union control, while that of the teacher is a matter of static taxpayer control, with a negative feedback.

A very serious shortage of secondary-school teachers now exists, and the shortage of science teachers is especially acute. The Steelman report [8] points out that out of 72,000 students enrolled in teacher training programs in the State of Michigan, only 164 majors and 172 minors qualified in a given year as teachers of science or mathematics. A vanishingly small number of physics majors plan to go into high-school teaching; why should they, when fame, fortune (relatively speaking), and social and intellectual prestige beckon elsewhere? Out of 200,000 students in 24 prominent colleges and universities, only 600 in a given year qualified for the teaching certificate in science and mathematics, and of these many went into industry at salaries far above those paid secondary-school teachers.[8]

Obviously we need to attract more professionally trained people to secondary-school teaching. Master's degrees in education considerably outnumber master's degrees in any other field of study, being 27 times the number of combined master's and doctor's degrees in biology, 12 times the number in physics, and six times the number in chemistry.

Approximately 50,000 people obtain college degrees of various sorts in education per year—the residue of those who do not go into other fields, including elementary school teaching, are available to staff the 25,000 secondary schools of the U. S. To fill all the national needs in those fields of science normally included in secondary-school curricula, namely mathematics, chemistry, biology, and physics, the total annual college output of scientists is about 30,000. Most of these go into other fields than secondary-school teaching of science. Is there not some way of increasing the number of chemists who teach secondary-school chemistry, and of physicists who teach high-school physics? Most young scientists in colleges do not bother to qualify for teaching certificates. Those people who do usually major in education. Equally important to the motivation of the student is motivation of the teacher, and more important than motivation of the science teacher to pedagogical method is his motivation to the spirit of science.

What the high-school student needs is a greater awareness of what scientists do professionally. In the words of A. J. Carlson of Chicago, "Gone from many biology courses are the basic, the impressive, the truly significant biological phenomena; the panorama of life through geological time, the marvelous interrelation of tissue structure and function in living bodies, the wondrous adaptations of flowers to pollinating insects, the mysterious migrations of birds, the beautiful precision of the hereditary mechanism of cells." More secondary-school teachers should come from schools of science, and fewer from schools of education. As a member of a school of science I should be diverting many able young scientists into secondary-school teaching. How can I conscientiously do this when each can choose from a number of jobs offering much more economic, social, and intellectual security?

Probably more than half our secondary schools cannot afford to hire a special teacher for the physical sciences. Most science teaching has to be assigned to teachers whose main interests lie in other fields. High-school teachers of science must do much extra work in the preparation and care of laboratory experiments, yet are expected to carry the same heavy teaching loads as other teachers. Laboratories cost money, and this again is an incentive to the school board to cut corners.

Even with able, well-paid teachers difficulty comes from the rapidity with which science advances and from the problems of a secondary-school teacher in keeping up with it so that his instruction is not outdated when midway in his teaching career. We find this difficulty even in universities, where the so-called "over-emphasis" on research can be ascribed in part to the fact that professional interest in current progress in the field invites personal participation, and gives the truest incentive for keeping abreast of science. Often high-power research men tend to lose interest in the teaching function except as applied to their own postgraduate assistants, and it is necessary to supplement them with men whose primary interest is teaching for its own sake. These men, surrounded by current pioneering research, nevertheless tend to find their attention so taken with details of pedagogy that they ultimately find themselves in a scientific backwater. How much more difficult, then, is the problem of the secondary-school teacher, who must go to such extreme efforts to attend a scientific meeting that he seldom does so.

Here is something which could readily be corrected. The teacher is encouraged by his principal, superintendent, and school board to attend meetings, all right, and to take special courses in the summer for advanced degrees, but these are almost always courses in the theory of pedagogy. It is easy, in the desire for improvement, to substitute the theory of the theory for the theory itself. To obtain that greatly needed extra $200 per year the secondary-school teacher is encouraged to take an MA in education. Most secondary-school teachers of science need more education in science than they do in education, for it is this, and this only, that will strike the spark which brings out the latent flame in the embryo scientists on whom they are operating. So much training in education is needed for teaching the unwilling student that we are likely to overlook the training in content needed for teaching the willing student.

At MIT we are now in the midst of an experiment on helping secondary-school teachers keep up to date. This summer, for the fourth time, 50 secondary-school science teachers from all over the country will gather for six weeks to attend the MIT Summer Program for Science Teachers, sponsored by the Westinghouse educational foundation. They receive from this foundation their tuition plus $200 for living expenses. Some bring their families, and 80 percent are housed in Institute dormitories. They are given no lectures on the theory of pedagogy or on methods of testing, but are attacked with two aims: (1) To bring them up to date in physics, chemistry, and biology, and give them a better idea of the actual status of professional work in these sciences, and (2) To inform them of the outstanding lacks and difficulties found when working with college freshmen in science, so that these can be remedied in secondary-school courses. The second purpose is achieved through a series of twelve demonstration lectures in physics, twelve in chemistry, and six in biology. The first aim is fulfilled by having a non-connected series of lectures and laboratory visits under various professional scientists in different fields. This program, which has been organized by and is under the direction of Professor Francis Sears of the MIT Department of Physics, is outstandingly successful, and the large number of applications makes it possible to select fewer than 50 percent of those who might benefit from it each year. Similar programs are going on elsewhere, but the number is still small, and needs to be enlarged.

Much useful information about the lacks of science in secondary schools comes from talking with these teachers. Many high-school teachers of physics have had only one semester of physics in college, though they have been required to take numerous courses in pedagogical theory.

I do not like the idea of teachers going on strike, but there is a strike of teachers now just as real as any strike of bricklayers, and much more important to the economy. After all, we can build our new buildings of aluminum and glass if it becomes necessary, but there is no substitute for the teacher, whether in elementary school, secondary school, or college. Large numbers of our best teachers are being lost to the service of the nation unborn, because they are attracted to more satisfactory and more remunerative fields than that of secondary-school teaching.

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[1] U. S. Office of Education. Statistical Summary of Education, 1947–48, p. 32, Table 16.

[2] John H. Lux and Leroy S. Moody, Chem. Eng. News, Dec. 17, 1951.

[3] M. H. Trytten, Jour. Engineering Educ., Oct. 1951, p. 77.

[4] Bulletin No. 9, Teaching of Science in Public High Schools, U. S. Office of Education.

[5] U. S. Office of Education, World Almanac 1852; Higher Education, Oct. 15, 1949.

[6] Manpower for Research, Report of the President's Scientific Research Board, Oct. 11, 1947, p. 95.