

SCIENCE

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THE TEACHING OF SCIENCE¹

THE prime claim of science to a place in the school curriculum is based upon the intellectual value of the subject matter and its application to life. This conception of education through science as the best preparation for complete living was Herbert Spencer's contribution to educational theory; and to its influence the introduction of science into the school is largely due. Spencer's doctrine was in accord with the principles of Pestalozzi as to the sequence in which facts and ideas should be presented and be related to stages of development, in order to be effective in creating or fostering natural interests in the mind of the child. Scientific instruction implies, therefore, not alone knowledge that is best for use in life, but knowledge adapted to the normal course of mental development. Both substance and method should be judged by the criterion of what is of greatest immediate worth or nearest to the pupil's interest at the moment. When this standard of psychological suitability is applied to the school science courses now usually followed, it must be confessed that they rarely reach it, many topics and much material being remote from the pupil's natural interests and needs.

The truth is that in the design of science courses for schools "trial-and-error" methods have been followed. In the absence of accurate knowledge these are the only possible methods of construction, but sufficient is now known of child psychology to produce a scheme of scientific instruction which represents not merely the views of advocates of particular subjects, but is biologically sound because it is in accord with the principles of mental growth, and, therefore, with those of

¹ From the address of the president of the Section of Educational Science, British Association for the Advancement of Science, Hull, September, 1922.

educational science. When instruction in science was first introduced into schools its character was determined by insight and conviction rather than by mental needs or interests; so later, when practical work came to be regarded as an essential part of such instruction, its nature and scope represented what certain authorities believed pupils should do, instead of what they were capable of doing with intelligence and purpose. Practical chemistry became drill in the test-tubing operations of qualitative analysis, and the result was so unsatisfactory from the points of view of both science and education that when Professor Armstrong put forward a scheme of instruction devised by him, in which intelligent experimentation took the place of routine exercises, acknowledgment of its superior educational value could not be withheld, and for thirty years its principles have influenced the greater part of the science teaching in our schools.

In its aims the "heuristic" methods of studying science energetically advocated by Professor Armstrong were much the same as those associated with the names of other educational reformers. Education in every age tends to a condition of scholasticism, and practical science teaching is no exception to this general rule, its trend being towards ritual, after which a revolt follows in the natural order of events. Comenius, with his insistence upon sense perception as the foundation of early training—"Leave nothing," he said, "until it has been impressed by means of the ear, the eye, the tongue, the hand." John Dury among the Commonwealth writers who urged that pupils should be guided to observe all things and reflect upon them; Locke, with his use of sciences not to bring about "a variety and stock of knowledge, but a variety and freedom of thinking"; and Rousseau who would "measure, reason, weigh, compare," not in order to teach particular sciences, but to develop methods of learning them—all these were in different degrees apostles of the same gospel of education according to Nature, and the development of a scientific habit of mind as the intention of instruction. What Rousseau persistently urged in this direction was clearly formulated by Spencer in the words, "Children should be led

to make their own investigations, and to draw their own inferences. They should be *told* as little as possible, and induced to *discover* as much as possible"—principles which cover all that is implied in what has since been termed "heuristic" teaching.

Professor Armstrong's particular contribution to educational science consisted in the production of detailed schemes of work in which these principles were put into practice. Ideas are relatively cheap, and it needs a master mind to make a coherent story or useful structure from them. This was done in the courses in chemistry outlined in reports presented to the British Association in 1889 and 1890, and the effect was a complete change in the methods of teaching that subject. "The great mistake," said Professor Armstrong, "that has been made hitherto is that of attempting to teach the elements of this or that special branch of science; what we should seek to do is to impart the elements of scientific method and inculcate wisdom, so choosing the material studied as to develop an intelligent appreciation of what is going on in the world." One feature of heuristic instruction emphasized by its modern advocate, but often neglected, is that which it presents to the teaching of English. Accounts of experiments had to be written out in literary form describing the purpose of the inquiry and the bearing of the results upon the questions raised, and wide reading of original works was encouraged. A few years ago English composition was regarded as a thing apart from written work in science, but this should not be so, and most teachers would now agree with the view expressed by Sir J. J. Thomson's committee on the position of natural science in the educational system of Great Britain that "All through the science course the greatest care should be taken to insist on the accurate use of the English language, and the longer the time given to science the greater becomes the responsibility of the teacher in this matter. . . . The conventional jargon of laboratories, which is far too common in much that is written on pure and applied science, is quite out of place in schools."

When heuristic methods are followed in the spirit in which they were conceived, namely,

that of arousing interest in common occurrences, and leading pupils to follow clues as to their cause, as a detective unravels a mystery, there is no doubt as to their success. No one supposes that pupils must find out everything for themselves by practical inquiry, but they can be trained to bring intelligent thought upon simple facts and phenomena, and to devise experiments to test their own explanations of what they themselves have observed. It is impossible, however, to be true to heuristic methods in the teaching of science and at the same time pay addresses to a syllabus. A single question raised by a pupil may take a term or a year to arrive at a reasonable answer, and the time may be well spent in forming habits of independent thinking about evidence obtained at first-hand, but the work cannot also embrace a prescribed range of scientific topics. Yet under existing conditions, in which examinations are used to test attainments, this double duty has to be attempted by even the most enlightened and progressive teachers of school science. There can, indeed, be no profitable training in research methods in school laboratories under the shadow of examination syllabuses. Where there is freedom from such restraint, and individual pupils can be permitted to proceed at their own speeds in inquiries initiated on their own motives, success is assured, but in few schools are such conditions practicable; so that, in the main, strict adherence to the heuristic method is a policy of perfection which may be aimed at but is rarely reached.

A necessary condition of the research method of teaching science is that the pupils themselves must consider the problems presented to them as worth solving, and not merely laboratory exercises. Moreover, the inquiries undertaken must be such as can lead to clear conclusions when the experimental work is accurately performed. It may be doubted whether the rusting of iron or the study of germination of beans and the growth of seedlings fulfils the first of these conditions, and the common adoption of these subjects of inquiry is due to custom and convenience rather than to recognition of what most pupils consider to be worth their efforts. It needed a Priestley and a Lavoisier to proceed from the rusting of iron

to the composition of air and water, and even such an acute investigator as Galileo, though well aware that air has weight, did not understand how this fact explained the working of the common suction pump. If research methods are to be followed faithfully, and what pupils want to discover about natural facts and phenomena is to determine what they do, then teachers must be prepared to guide them in scores of inquiries both in and out of the laboratory. Under the exigencies of school work it is impracticable to contemplate such procedure, and all that can be usefully attempted is to lead pupils to read the book of Nature and to understand how difficult it is to obtain a precise answer to what may seem the simplest question.

The mission of school science should not, indeed, be only to provide training in scientific method—valuable as this is to every one. Such training does cultivate painstaking and observant habits, and encourages independent and intelligent reasoning, but it can not be held in these days that any one subject may be used for the general nourishment of faculties which are thereby rendered more capable of assimilating other subjects. Modern psychology, as well as everyday experience, has disposed of this belief. If the doctrine of transfer of power were psychologically sound, then as good a case could be made out for the classical languages as for science, because they also may be taught so as to develop the power of solving problems and of acquiring knowledge at the same time. When, therefore, advocates of particular courses of instruction state that they do not pretend to teach science, but are concerned solely with method, they show unwise indifference to what is known about educational values. Locke's disciplinary theory—that the process of learning trains faculties for use in any fields, and that the nature of the subject is of little consequence—can no longer be entertained. It has now to be acknowledged that information obtained in the years of school life is as important as the process of obtaining it; that, in other words, subject matter as well as the doctrine of formal discipline must be taken into consideration in designing courses of scientific instruction which will conform to the best educational principles.

So long ago as 1867 the distinction between subject and method was clearly stated by a Committee of the British Association, which included among its members Professor Huxley, Professor Tyndall and Canon Wilson. It was pointed out that general literary acquaintance with scientific things in actual life and knowledge relating to common facts and phenomena of nature were as desirable as the habits of mind aimed at in scientific training through "experimental physics, elementary chemistry and botany." The subjects which the committee recommended for scientific information, as distinguished from training, comprehended "a general description of the solar system; of the form and physical geography of the earth, and such natural phenomena as tides, currents, winds and the causes that influence climate; of the broad facts of geology; of elementary natural history with especial reference to the useful plants and animals; and of the rudiments of physiology." If we add to this outline a few suitable topics illustrating applications of science to everyday life, we have a course of instruction much more suitable for all pupils as a part of their general education than what is now commonly followed in secondary schools: It will be a course which will excite wonder and stimulate the imagination, will promote active interest in the beauty and order of nature, and the extension of the kingdom of man, and provide guidance in the laws of healthy life.

The purpose of this kind of instruction is, of course, altogether different from that of practical experiment in the laboratory. One of the functions is to provide pupils with a knowledge of the nature of everyday phenomena and applications of science, and of the meaning of scientific words in common use. Instead of aiming at creating appreciation of scientific method by an intensive study of a narrow field, a wide range of subjects should be presented in order to give extensive views which can not possibly be obtained through experimental work alone. The object is indeed almost as much literary as scientific, and the early lessons necessary for its attainment ought to be within the capacity of every qualified teacher of English. Without acquaintance with the com-

mon vocabulary of natural science a large and increasing body of current literature is unintelligible, and there are classical scientific works which are just as worthy of study in both style and substance as many of the English texts prescribed for use in schools. We all now accept the view that science students should be taught to express themselves in good English, but little is heard of the equal necessity for students of the English language to possess even an elementary knowledge of the ideas and terminology of everyday science, which are vital elements in the modern world, and which it is the business of literature to present and interpret.

So much has been, and can be, said in favor of broad courses of general informative science in addition to laboratory instruction and lessons which follow closely upon it, that the rarity of such courses in our secondary schools is a little surprising at first sight. Their absence seems to be due to several reasons. In the first place, the teachers themselves are specialists in physics, chemistry, biology or some other department of science, and they occupy their own territory in school as definitely as Mr. Eliot Howard has shown to be the behavior-routine of birds in woods and fields. You may, therefore, have a teacher of physics who has taken an honors degree and yet knows less of plant or animal life than a child in an elementary school where nature study is wisely taught; and, on the other hand, there are teachers of natural history altogether unacquainted with the influence of physical and chemical conditions upon the observations they describe or the conclusions they reach. Natural science as a single subject no longer exists either in school or university, and with its division and sub-division has come a corresponding limitation of interest. No man can now be considered as having received a liberal education if he knows nothing of the scientific thought around him, but it is equally true that no man of science is scientifically educated unless his range of intellectual vision embraces the outstanding facts and principles of all the main branches of natural knowledge. It can not reasonably be suggested that this general knowledge of science should be acquired by all

if teachers of science themselves do not possess it. During the past thirty years or so there has been far too much boundary-marking of science teaching in school on account of the specialized qualifications of the teachers. What is wanted is less attention to the conventional division of science into separate compartments designed by examining bodies, and more to the whole field of nature and the scientific activities by which man has transformed the world; and no teacher of school science should be unwilling or unqualified to impart such instruction to his pupils.

Where such teachers do exist, however, they are compelled by the exigencies of examinations to conform to syllabuses of which the boundary lines are no more natural than those which mark political divisions of countries on a map of the world. All that can be said in favor of the delimitation of territory is that it is convenient; the examiner knows what the scope of his questions may be, and teachers the limits of the field they are expected to survey with their pupils. While, therefore, it may be believed that a general course of science is best suited to the needs of pupils up to the age of about sixteen years, examining authorities recognize no course of this character, and very few schools include it in the curriculum. Expressed in other words, the proximate or ultimate end of the instruction is not education but examination, not the revealing of wide prospects because of the stimulus and interest to be derived from them, but the study of an arbitrary group of topics prescribed because knowledge of them can be readily tested. It may be urged that this is the only practicable plan to adopt if a science course is to have a defined shape, and not, like much that passes for nature study, merely odds and ends about nature, without articulation or purpose. Acceptance of this view, however, carries with it the acknowledgment that expediency rather than principle has to determine the scope and character of school science, which is equivalent to saying that science has no secure place in educational theory. I prefer to believe that a school course of general science can be constructed which is largely informative and at the same time truly educational, but it must provide what is best adapted to enlarge the

outlook and develop the capacity of the minds which receive it, and not be determined by the facilities it offers for examinational tests.

A third reason for the relative absence of general scientific education in schools is the demands which the teaching might make upon apparatus and equipment. Simple quantitative work in physics, chemistry or botany can be done in the laboratory with little apparatus, and a single experiment may occupy a pupil for several teaching periods. To attempt to provide the means by which all pupils can observe for themselves a wide range of unrelated facts and phenomena belonging to the biological as well as to the physical sciences is obviously impracticable, and would be educationally ineffective. Experiments carried out in the laboratory should chiefly serve to train and test capacity of attacking problems and arriving at precise results just as definitely as do exercises in mathematical teaching. But knowledge by itself, whether of quantitative or qualitative character, is not sufficient, and it becomes power only when it is expressed or used. Every observation or experiment carries with it, therefore, the duty of recording it clearly and fully in words or computations, or both, and if this is faithfully done laboratory work of any kind may be made an aid to English composition as well as an incentive to independent inquiry and intelligent thought.

It is very difficult, however, to devise a laboratory course of general science which shall be both coherent and educative; shall be, in other words, both extensive in scope and intensive in method. I doubt, indeed, whether any practical course can perform this double function successfully. Probably the best working plan is to keep the descriptive lessons and the experimental problems separate, using demonstrations in the class-room as illustrations, and leaving the laboratory work to itself as a means of training in scientific method or of giving a practical acquaintance with a selected series of facts and principles. The main thing to avoid is the limitation of the science teaching to what can be done practically; for no general survey is possible under such conditions. Even if two thirds of the time available for scientific instruction be devoted to laboratory experiment and questions provoked by it, the

remaining third should be used to reveal the wonder and the power and the poetry of scientific work and thought; to be an introduction to the rainbow-tinted world of nature as well as provide notes and a vocabulary which will make classical and contemporary scientific literature intelligible. If there must be a test of attention and understanding in connection with such descriptive lessons, because of the spirit of indifference inherent in many minds—young as well as old—let it be such as will show comprehension of the main facts and ideas presented and knowledge of the meaning of the words and terms used. In this way descriptive lessons may be used to provide material for work and active thought, and light dalliance with scientific subjects avoided.

It may be urged that no knowledge of this kind has any scientific reality unless it is derived from first-hand experience, and this is no doubt right in one sense; yet it is well to remember that science, like art, is long while school life is short, and that though practical familiarity with scientific things must be limited, much pleasure and profit can be derived from becoming acquainted with what others have seen or thought. It is true that we learn from personal experience, but a wise man learns also from the experience of others, and one purpose of a descriptive science course should be to cultivate this capacity of understanding what others have described. As in art, or in music, or in literature, the intention of school teaching should be mainly to promote appreciation of what is best in them rather than to train artists, musicians or men of letters, so in science the most appropriate instruction for a class as an entity must be that which expands the vision and creates a spirit of reverence for nature and the power of man, and not that which aims solely at training scientific investigators. It should conform with Kant's view that the ultimate ideal of education is nothing less than the perfection of human nature, and not merely a goal to be obtained by the select few.

The sum and substance of this address is a plea for the expansion of scientific instruction in this humanizing spirit, for widening the gateway into the land of promise where the

destinies of the human race are shaped. It is the privilege of a president to be to some extent pontifical—to express opinions which in other circumstances would demand qualification—and to leave others to determine how far the doctrines pronounced can be put into practice in daily life. I do not, therefore, attempt to suggest the outlines of courses of science teaching for pupils of different ages, or for schools of different types; this has been done already in a number of books and reports, among the latter being the report of Sir J. J. Thomson's committee on the position of natural science, the report of the British Association committee on science teaching in secondary schools, Mr. O. H. Latter's report to the Board of Education on science teaching in public schools, the "science for all" report and syllabus issued by the Science Masters' Association, a Board of Education report on "Some Experiments in the Teaching of Science and Handwork in Certain Elementary Schools in London," and one prepared for the board by Mr. J. Dover Wilson on "Humanism in the Continuation School." What has been said in this address as to the need for extending the outlook of customary scientific instruction beyond the narrow range of manual exercises, manipulative dexterity, experimental ritual or incipient research, can be both amplified and justified from these reports. I want science not only to be a means of stimulating real and careful thinking through doing things, but also a means of creating interest and enlarging the working vocabulary of the pupils and thus truly increasing their range of intelligence. So may scientific instruction be made a power and an inspiration by giving, in the words of the Book of Wisdom (vii: 16-20):

an unerring knowledge of the things that are,
To know the constitution of the world and the
operation of the elements;
The beginning and end and middle of times,
The alternations of the solstices and the changes
of seasons,
The circuits of years and the positions of stars;
The nature of living creatures and the raging of
wild beasts,
The violences of wind and the thoughts of men,
The diversities of plants and the virtues of roots.

When school science has this outlook it will lie closer to the human heart than it does at present, and a common bond of sympathy will be formed between all who are guiding the growth of young minds for both beauty and strength. So will the community of educational aims be established and the place of science in modern life be understood by a generation which will be entrusted with the task of making a new heaven and a new earth. If these trustees for the future learn to know science in spirit as well as in truth we may look forward with happy confidence to the social structure they will build, in which knowledge will be the bedrock of springs of action and wisdom will make man the worthy monarch of the world.

RICHARD GREGORY

FROG AND TOAD TADPOLES AS SOURCES OF INTESTINAL PRO- TOZOA FOR TEACHING PURPOSES

MANY teachers of protozoology and invertebrate zoology use frogs for the purpose of obtaining intestinal protozoa for class use, but it does not seem to be generally known that the tadpoles of frogs and toads are even more valuable than the adults as sources of material. Unfortunately tadpoles are most abundant late in the spring and in early summer when classes are usually not in session, but two species of frogs that are more or less common throughout the United States pass two or more seasons in the tadpole stage and hence are available in the autumn and, in the southern part of the country, at any time of the year; these are the green frog, *Rana clamitans*, and the bullfrog, *R. catesbeiana*. The former is common throughout eastern North America, inhabiting swamps and large and small ponds; the latter has a similar distribution but is limited to swamps and the larger and deeper ponds. Tadpoles should be looked for in these habitats. The identification of these, so far as their use as material for intestinal protozoa is concerned, is of little importance, but it may be stated here that the tadpoles of the two species are very similar and difficult to distinguish from each other. Full descriptions of them are given by

Wright (1914). A breeding place once found will serve as a source of supply year after year. Sample tadpoles should be collected some time before the class meets so as to determine the incidence of infection and numbers present of the various species of protozoa, since this varies from year to year. The specimens for class use may be collected several days before they are needed but should not be kept in the laboratory for more than a week or two since they tend to lose their infections under laboratory conditions. The writer has found dishes about ten inches in diameter and three inches deep containing a quart of tap water to be suitable for about twenty tadpoles each. The dishes should not be covered with glass plates, but the water should be changed every day or two. Tadpoles may be killed very quickly, as adult frogs usually are, by destroying the brain and spinal cord with a heavy needle. The ventral body wall can then be opened from the anterior to the posterior end. The intestine is coiled within the body cavity, being several hundred millimeters in length. The rectum, or posterior portion of the alimentary tract, is tightly coiled and is separated from the intestine by a constriction. The different species of intestinal protozoa are rather definitely distributed within the intestine and rectum. The anterior portion of the intestine is inhabited by a flagellate, *Giardia agilis*; in various parts of the intestine and rectum *Endameba ranarum* may be found; the rectum is the principal habitat of two genera of ciliates, *Opalina* and *Nyctotherus*, of two genera of flagellates, *Trichomonas* and *Hexamitus*, and of several green flagellates resembling members of the genera *Euglena* and *Phacus*. To study any of these species in the living condition, the part of the digestive tract containing them should be teased out in a drop of 0.7 per cent. salt solution and covered with a cover glass. Any of the species mentioned can be found with low magnification, such as obtained with a 16 mm. objective and a number 5 ocular. To study the details of most of these protozoa, however, the Schaudinn iron-haematoxylin method is necessary. This in brief is as follows: Spread the intestinal or rectal contents in a thin layer over about one half the area of