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TEACHING SCIENCE IN HIGH SCHOOL--WHAT IS WRONG. PAPER PRESENTED AT THE AAAS MEETING, DECEMBER 29, 1967, NEW YORK.

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DESCRIPTORS- *DISCOVERY LEARNING, *INSTRUCTION, *LEARNING, *PROGRAMED INSTRUCTION, *REINFORCEMENT, *SECONDARY SCHOOL SCIENCE, *SCIENCE EDUCATION, AUDIOVISUAL AIDS, EDUCATIONAL PROBLEMS, SCIENTIFIC MANPOWER, AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE,

ADVOCATED ARE RESEARCH IN SCIENCE TEACHING AND CHANGES IN EDUCATIONAL PRACTICES WHICH WILL PROMOTE THE RECRUITMENT OF ABLE SECONDARY SCHOOL STUDENTS INTO CAREERS IN SCIENCE. PART 1 OF THE PAPER DEVELOPS SUPPORT FOR THE ASSERTION THAT THE IMMEDIATE EFFECTS OF CERTAIN CLASSROOM PRACTICES ARE REINFORCING TO THE STUDENT AND TEACHER ALIKE, WHILE THEIR LONG-TERM WEAKNESSES ARE NOT SEEN, AND THE PRACTICES THEREFORE FLOURISH. MANY CURRENT INSTRUCTIONAL PRACTICES ARE ANALYZED AND SERIOUS QUESTIONS ARE RAISED AS TO THE LIMITED USE WHICH IS MADE IN TEACHER PREPARATION AND IN CLASSROOM PRACTICE OF THE KNOWLEDGE AVAILABLE ON THE PROCESSES INVOLVED IN LEARNING AND TEACHING. PART 2 DISCUSSES INSTRUCTIONAL PRACTICES WHICH THE AUTHOR BELIEVES WILL CONTRIBUTE TO IMPROVE SCIENCE INSTRUCTION. THE DESIRABILITY OF IDENTIFYING AND DEFINING TERMINAL BEHAVIORS AND THE UTILIZATION OF PROGRAMED INSTRUCTION IN ATTAINING THESE OUTCOMES ARE ELABORATED. CLASSROOM MANAGEMENT AND THE UTILIZATION OF VARIOUS FORMS OF REINFORCEMENT ARE RELATED TO THEIR EFFECT ON THE DEVELOPMENT OF DESIRED STUDENT BEHAVIORS. IT IS CONCLUDED THAT A GENUINE IMPROVEMENT IN SCIENCE TEACHING WILL BE DIFFICULT, BUT IT MUST BE ACCOMPLISHED IF WE ARE TO CIRCUMVENT THE DISASTER WHICH WILL FOLLOW IF WE FAIL TO RECRUIT A LARGE SEGMENT OF OUR MOST INTELLIGENT AND DEDICATED MEN AND WOMEN FOR SCIENCE VOCATIONS. (DS)

American Association for the Advancement of Science
Friday, December 29, 4:15 p.m. Ceepary Auditorium of Rockefeller University

Teaching Science in High School -- What is Wrong?

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The scientific community faces a serious problem. Science and technology are growing exponentially, but the number of young people going into science is not. A surprisingly small percentage of higb-school students go on to college expressing an interest in becoming scientists and many of these eventually shift to other fields. There is already an acute shortage which could prove disastrous, not only for science itself but for a way of life which depends on science to an ever greater extent.

Possibly the life of the scientist has lost some of its glamour. It may offer less chance for personal satisfaction, and its exciting moments may be reserved for those who have had extensive preparation. Even so, the main fault probably lies with education. Good teaching should give an accurate account of what science is and does, of what one scientist may contribute to the world, and of the genuine excitement of those who enjoy science as the great art of the twentieth century. Above all, it should recruit the scientists of the future, finding the right people, giving them the basic knowledge and skills they need, and providing the satisfactions which will make them dedicated and creative. Only if it does so can we hope to find those who will practice science in our universities, institutes, industries, and governmental services, and who will teach science in our schools and colleges and thus keep the enterprise going. Only effective teaching can create that large pool from which, in each generation, a few great scientists are drawn.

The problem has not gone unnoticed. For the past ten or fifteen years, education as a whole has been sharply criticized and constructive suggestions have been made. We are all familiar with proposed remedies. Education needs support, and support means money, and the money is to be used in a variety of ways. We need more and better schools. We need to recruit and hold better teachers, selecting them through better systems of qualification and making them more competent in the fields in which they teach. We need to give all qualified students their chance -- selecting them more impartially, supporting them financially, and removing social and racial barriers. We need more and better capital equipment -- such as texts, workbooks, films, and audio-visual devices, including teaching machines and television. We need to change our curriculums not simply in line with the standard complaint that what is wrong with education is that we are teaching the wrong things, but in a genuine effort to bring what is taught up to date and to make a sensible selection among the things to be taught.

High-school science teaching has been singled out for special effort, and there is no doubt that important steps have been taken. But there is not yet any great change. The curve showing the number of students going into science has not turned sharply upward. Possibly it is too soon to expect results. Educational practices usually change slowly, and we may yet see progress. But some possible reasons why improvement has not been more dramatic should be pointed out.

There is a curious omission in this list of educational needs. Nothing is said about a better understanding of the processes involved in learning and teaching or the possibility of improving them. No suggestion is made that we ought to know more about what is happening when a teacher teaches and a student

learns. On the contrary, the issue is avoided in most current educational reforms. Pedagogy is a dirty workd, and courses in educational "method? are discounted, if not ridiculed. This is a serious mistake. As science itself has so abundantly demonstrated, the power of any technology depends upon an understanding of its basic processes. We cannot really improve teaching until we know what it is.

The most casual attitude toward a better understanding of instruction is evident at all levels of education. You will not find anything like a medical school, law school, or business school for those who want to be college teachers. No professional training is felt to be necessary. Preparation for grade and high-school teaching is scarcely more explicit. Schools of education themselves no longer actively promote pedagogy or method as formalized practice. The beginning teacher serves an apprenticeship. He watches other teachers and learns to behave as they behave, and eventually he may profit from his own classroom experience. In the long run high-school teachers, like college teachers, teach simply as they themselves have been taught, as they have seen others being taught, or as experience dictates.

What is learned from classroom experience is perhaps likely to be more useful than formalized rules and prescriptions, but the classroom is not an ideal source of educational wisdom. On the contrary, it can be seriously misleading. Francis Bacon once formulated his famous Idols -- the false notions or fallacies which led to bad thinking. I have suggested (1) that we should add another to his list: the Idols of the School. The Idol or Fallacy of the Good Teacher is the belief that what a good teacher can do, any teacher can do. Some people are socially skillful. They are good judges of character and get along well with people, and they make good teachers. The trouble is, we do not know why. Like the old time doctor, they practice an art which has not been analysed and can seldom be communicated. In the hands of a good teacher a new text, a new set of materials, or a new teaching method may be dramatically successful, but it does not follow that the text, material, or method will be successful in the hands of teachers at large.

The complementary Fallacy of the Good Student is the belief that what a good student can learn, any student can learn. Some students are highly intelligent and well-motivated. They know how to study effectively, and they learn without being taught or even when taught by a bad teacher. A text, a set of materials, or a method which works well with them will not necessarily be a success with all students.

For many years educational journals, school bulletins, and the popular media have reported examples of effective teaching. They have portrayed lively classes in which teachers and students are working together in harmony and the students obviously learning a great deal. Everyone is pleased. The teachers take satisfaction in what they are doing, the students enjoy themselves and make progress, and administrators and parents are delighted. But is it not time to ask why are these examples not more widely copied? Why, by this time, is not all teaching equally pleasant and profitable? The answer is probably to be found in the Idols of the School. We are looking at good teachers or good students or both, but not at practices which have been analysed or can be communicated. We cannot improve education by finding more good teachers and more good students. For the moment, it may be well to forget them, as we may safely do since they do not need our help. Let us turn instead to the design of educational practices which will permit all teachers to teach well, and under which all students will learn as effectively as their talents permit.

A first step is to recognize how misleading classroom experience may be as a source of educational wisdom. It has one outstanding defect: the teacher seldom sees what he has done. The significant effects of teaching lie in a distant future, when students make use of what they have learned, and it is a future the teacher seldom sees. He knows nothing of what happens to most of his students. His behavior is influenced instead by short-term results, many of which contribute nothing to long-term goals and may actually conflict with them.

The excited classroom provides a good example. No teacher enjoys students who are disorganized, inattentive, lethargic, or resentful. But the teacher may produce lively and attentive students in ways which have little to do with what or how much they are learning. In a familiar -- perhaps too familiar -- classroom practice, the teacher asks questions and the students answer. The students are rewarded for right answers and punished for wrong, and anything a student does to be called on when he knows the answer or overlooked when he does not will be reinforced. The teacher is reinforced either by right answers which show that he has been teaching successfully or by wrong if he must maintain control of the class through a threat of punishment, and anything he may do to get a right answer when he wants a right answer or a wrong one when he wants a wrong one will be reinforced.

These are the essential conditions for a complex game in which teacher and students attempt to outguess each other. The student who knows an answer waves his hand, and a teacher who wants a right answer calls on him, but he calls on someone else if he wants a wrong answer, and the student who does not know the answer than raises his hand to avoid being called on, the student who knows the answer keeps his hand down, hoping to get a chance, and so on. The class is excited, the teacher is in control, and everyone may be having a good time. But the game may be quite unrelated to any subject being taught -- indeed, it is the same for all subjects -- and its educational value may be questioned. It may have a motivational effect on some students, but it is not characteristic of thoughtful discussion or study, and its long-term effects may be negligible or harmful. A dull, lethargic class is no doubt the sign of a bad teacher, but an excited class is not necessarily the sign of a good one.

The hand-waving game may seem too trivial to deserve notice, but the same kind of game is played in classroom discussion. The modern Socrates, like his famous predecessor, plays cat and mouse with his students, pretending to misunderstand, constructing absurd paraphrases, making suggestions which lead his listeners into error, making ironic comments which amuse some of his listeners at the expense of others, and so on. If he is skillful, his students will protest, disagree, insist, and defend themselves in lively ways. All this may be valuable in teaching argumentation and in giving students reasons for acquiring the facts they need for the sake of argument, but like the hand-waving game, it may be unrelated to subject matter. It certainly gives the student a wrong impression of scientific thinking. <u>It is true that scientists occasionally discuss things among themselves, but the creative interchanges are more likely to be between men and things than between men and men.</u> The Great Conversation has been going on for more than two thousand years, and it has not yet been notably productive of useful information or wisdom. To suggest to students that science is a kind of running debate is to risk selecting potential debaters rather than potential scientists.

Both teacher and students can be similarly misled by practices designed primarily to making science interesting. We like to have our students take an interest in things because they are then likely to learn something about them, and the effort to make a subject interesting is no doubt helpful, but it is a

mistake to confuse it with teaching. In a recent review of a book on the mathematical curriculum (2), the reviewer insisted that remarks on the psychology of teaching should "confine themselves (my italics) to observing that mathematics teaching (indeed, all teaching) must make the subject matter attractive." And how often is it said that the good teacher is simply one who knows his field and can make it interesting! But teaching is much more than arousing interest, and arousing interest may in fact conflict with good teaching.

A simple example concerns attention. A student who is not paying attention is obviously not learning, and anything the teacher can do to attract attention is therefore reinforced. Audio-visual materials, texts with colored pictures and charts, animated films, demonstration experiments full of surprises -- these are often used just because they attract and hold the student's attention. Advertisers and the entertainment industry face a similar problem and solve it in similar ways. But to attract attention is to deprive the student of the chance to learn to pay attention. The important thing is to discover that interesting things happen when one attends to something which, on its face, is not interesting at all. We do not want students who read books only when they are printed in four colors, or who watch films or demonstrations only when something interesting is always happening. We want students who read black and white pages because something interesting happens when they do so, who watch films and demonstrations which are no more interesting than nature itself until close observation shows how interesting they really are. Materials which have been designed to appeal to a student's current interests -- the physics of the tennis court, the chemistry of the kitchen -- miscarry in the same way. Faraday became interested in electricity when he read an article in the encyclopedia, and it was not entitled "Electricity for young Britons."

I am not saying that a student should not be interested in what he is studying, or that interesting aspects should not be pointed out, but in overemphasizing the merely interesting aspects of science, we mislead the student about what he is to find when he pursues science further, and we should not be surprised that he drops out when he finds it. The things which interest the mature scientist throughout a lifetime of dedicated research are not the things which interest the layman or the beginning student. It is characteristic of the successful scientist, for example, that he continues to work for long periods when nothing interesting is happening. That kind of interest can be imparted to the student, as we shall see, but not by making a subject interesting.

Another practice the effect of which is immediately rewarding to the teacher but the ultimate consequences of which may be questioned is letting the student discover science for himself. This was Rousseau's great principle, developed in his book Emile. The student should learn from nature, not from what others have said about nature; he should go directly to the facts, to things, which alone are incorruptible. It is supported by Pascal's earlier observation that the arguments we discover for ourselves are better understood and remembered than those we get from others. Discovery as a method of teaching seems particularly appropriate in science where discoveries are the great events. The scientist works in order to discover, and he continues to work so long as there is a chance to discover. Why should not the student have the same motivation?

We cannot mean, however, that the student is to discover all of science for himself -- or even any appreciable part of it. Science is a vast accumulation of the discoveries of a great many men. It must be transmitted from one

generation to another--in books, charts, tables, and so on, but also in the behavior imparted to new members of a culture. Education is charged with the transmission of knowledge, and it cannot possibly fulfill its obligation simply by arranging for rediscovery. Whether we like it or not, a great deal of science must be taught, and we raise a serious obstacle when we suggest to the student that it is beneath his dignity to learn what someone else already knows. How much of science is to be taught, how much is simply to be made available in recorded form, and how much is to be left to rediscovery are questions concerning the available time and energy. The answers must take into account the efficiency of teaching methods.

The problem is made particularly difficult because scientific knowledge changes so rapidly. Textbooks and other records go out of date, and so do the behavioral repertoires imparted through instruction, but we cannot solve that problem by refusing to write books or to teach. We must be prepared to change our books and to teach in such a way that the behavior of our students will change as occasion demands. Letting the student discover things for himself is no solution to this problem either, because what he discovers will also soon be out of date.

Of course we want to encourage students to inquire, explore, and discover things for themselves, and we want to teach them to do so efficiently. We must teach scientific method as well as facts. Verbal methods have been carefully formulated by mathematicians, logicians, statisticians, and others, and are usually part of a science curriculum. The nonverbal day-to-day behavior of the scientist in his laboratory has been sadly neglected, and it is here that techniques of discovery are more likely to be relevant. We no doubt need to know more about them if we are to teach them well, but even so there is no reason why they should be taught by the discovery method.

Indeed, it is not likely that they <u>are</u> taught by that method. The guided discoveries of the classroom bear only a vague resemblance to genuine scientific discovery. The archetypal pattern of this kind of teaching is the scene in Plato's <u>Mano</u> in which Socrates leads the slave boy through Pythagoras's theorem for doubling the square. This is still hailed as a great educational innovation, but the fact is that the slave boy learned nothing. There was not the remotest chance that he could go through the proof himself when Socrates was through with him, and even if he could have done so, his behavior in assenting to Socrates' suggestions almost certainly had nothing in common with the steps which led Pythagoras to his statement of the theorem. Polya (3) has published a delightful account of how, with a class of high-school students, one might tease out the formula for the diagonal of a parallelepiped, but the teacher's hints, suggestions, corrections, and heuristic exhortations do not give a very convincing picture of the conditions under which the original discovery must have been made. A few students no doubt benefit from this kind of teaching in the hands of a good teacher. They experience some of the delight of making a discovery, and it may sustain them in further work. Even so, they are not necessarily then more likely to make other discoveries by themselves. Meanwhile, all the other students in the class have received a particularly confusing presentation. Although the moment of discovery is important in the life of a scientist and may explain his dedication, it is a rare event and cannot explain the quality or nature of most of his behavior.

In summary, then, the immediate effects of certain classroom practices are reinforcing to student and teacher alike, while their long-term weaknesses are not seen, and the practices therefore flourish. There are no doubt other reasons. Contemporary education is in a state of transition. It is a transition in the right direction, but it has a long way to go. We are in the process

of rejecting methods which have long dominated the field. We do not want our students to study primarily to avoid punishment nor do we want to impose upon the teacher the necessity of maintaining a sustained threat. A dictatorial, despotic teacher--an authority in a political as well as a scholarly sense--is out of place in modern life. We want learning to mean more than practice, drill, or rote memorizing. And it is not surprising, therefore, that we should turn first to making science attractive, engaging the student in discussion, giving him materials which arouse his interest, and letting him discover things for himself. But as enjoyable as these things may be--for teacher and student alike--the fact remains that they are not really effective alternatives. The proof is that we find ourselves forced back again and again to old coercive patterns. In spite of all our efforts, it is still true that our students learn mostly in order to avoid the consequences of not learning. The commonest pattern in high school as well as college is still that of "Assign-and-test." We tell the student what he is to learn and hold him responsible for learning it by making a variety of unhappy consequences contingent on his failure. In doing so we may give him some reason to learn, but we are not teaching him.

Our failure is clear in the frequency with which educators conclude that a teacher cannot really teach but can only help the student learn. This is a disastrous philosophy. It can be asserted only of methods which have so far been tried, but it is used as an argument against trying new ones. It is not only a confession of failure, it is also a form of exculpation. We admit that we cannot teach in order to avoid confessing that we have failed to do so. We can thus continue to maintain, as teachers have maintained for centuries, that it is always the student who fails, not the teacher.

We can discard coercive practices only when we have found satisfactory replacements. An important first step in the search for better ways of teaching is to define our terms. What is teaching? What is happening when a student learns? Traditional theories of education almost always answer questions of that sort in mentalistic ways. The student is said to begin with a desire to learn and a natural curiosity of which the teacher must take advantage. The teacher must exercise the student's faculties, strengthen his reasoning powers, develop his cognitive styles and skills, let him discover strategies of inquiry. The student must acquire concepts, come to see relations, and have ideas. He must take in and store information in such a form that it can be retrieved when needed. And so on. Statements of educational policy are replete with expressions of this sort. It would be a mistake to underestimate their power, for they are supported by ancient systems of psychology which have become imbedded in our language and by vestigial cognitive theories. It is therefore hard to realize that they are either metaphors which inadequately represent the changes taking place in the student's behavior or explanatory fictions which explain nothing. They do not tell the teacher what to do in order to bring about changes in his students, nor do they give him any way of knowing whether he has done so. If these were indeed the tasks of the teacher, we should have to agree that he cannot really teach. It is even doubtful whether he could help the student learn.

A much more promising approach is to look at the behavior itself--the behavior from which mentalistic states and processes are inferred and which they so inadequately describe and explain. The basic question--in its crudest form--is this: What do we want the student to do as a result of having been taught? (It is no answer to cite the examinations he is to pass, for they are only samples of his behavior, and no matter how reliable they may be, they are, we hope, very small samples indeed of what he actually learns.) To say that we

want the student to "behave like a scientist" is on the right track, but it is only a start. For how <u>does</u> a scientist behave? The answer will be nothing less than an epistemology--a theory of scientific knowledge. It must in fact be more: we need an empirical description of the behavior of the scientist at work, in all its myriad forms.

Such a description is not to be had for the asking. It is, of course, an extraordinarily difficult field, and we have not advanced very far in analyzing it just because we have so often been seduced by metaphor. If we announce that we are interested in giving the student a thorough knowledge of chemistry, a grasp of its structure, or an understanding of its basic relations, we shall be endlessly admired. If, instead, we specify things we want our students to do, we shall risk being thought mechanical and shallow, even though the things we list are precisely the things from which his understanding or grasp of the structure of the subject is inferred. Unfortunately, there is nothing about behavior which evokes the mystery which has always attached to mind, but it is important to remember that we stand in awe of mind just because we have been able to do so little about it.

To remove the mystery, we must define our goals in the most explicit way. And we can then begin to teach. Having specified the terminal behavior we want our students to exhibit, we can proceed to generate it. One way is through programmed instruction--a contribution to education which has been widely misunderstood. Many educational theorists have insisted that it is nothing new and have tried to assimilate it to earlier theories and practices. We are told that it is simply a matter of breaking the material to be learned into easy steps, arranging steps in a logical order with no omissions, making sure the student understands one step before moving on to another, and thus making sure that he will be frequently successful. All these things are done in the act of constructing a good program, but they still miss the central point.

Programmed instruction is primarily a way of using recent advances in our understanding of human behavior. We want to strengthen certain kinds of behavior in our students, and it is therefore relevant that behavior is strengthened when it is followed by certain kinds of consequences. A response which produces a so-called positive reinforcer or terminates a negative is more likely to occur again under similar circumstances. We can use this principle of "operant conditioning" to strengthen the behavior of our students simply by arranging reinforcing consequences--in other words, making available reinforcers contingent on their behavior. This is often said to be nothing more than reward and punishment, and there is certainly a connection. But contingencies of reinforcement have now been submitted to an extensive experimental analysis, in the light of which we can say that the traditional concept of reward is about as close to operant conditioning as traditional concepts of heat, space, or matter are to contemporary scientific treatments.

Teaching may be defined as the arrangement of contingencies of reinforcement which expedite learning. Learning occurs without teaching--fortunately--but improved contingencies speed the process and may even generate behavior which would otherwise never occur. Programmed instruction is concerned with the fact that we cannot reinforce behavior until it occurs. We cannot simply wait for our student to behave in a given way, particularly in the very complex ways characteristic of a scientist. Somehow or other we must get him to behave. Our culture has devised relevant techniques quite apart from educational uses. We can resort to verbal instruction, for example, simply telling the student what to do, or show him what to do and let him imitate us. We shall not get very far, however, by inducing the student to engage in complex terminal behavior. We may execute the behavior, but he will be much too

dependent upon being shown or told. We begin instead with whatever behavior the student has available, and we selectively reinforce any part which contributes to the terminal pattern or which makes it more likely that the student will behave in ways which contribute to it. The devices we use to evoke the behavior can then be more easily withdrawn, so that the terminal behavior will appear upon appropriate occasions without help. A high degree of technical knowledge is needed to do all this.

Many instructional programs have been written by those who do not understand these principles, and it is an unhappy reflection on the state of education today that they are still probably better than unprogrammed materials, but they give a wrong impression. Even a good program may be misleading to anyone who is already expert in the field, because the effect on a new learner is not easily appreciated. Anyone who wants to get the feel of programmed instruction should try his hand at a good program in an unfamiliar field. A colleague whose work had begun to move in the direction of biochemistry worked through an excellent program in that field. "In three days," he told me, "I knew biochemistry!" He was exaggerating, of course, as we both knew, but he was expressing very well the almost miraculous effect of a good program.

A further misunderstanding has arisen from the fact that industry and the Armed Services have taken up programmed instruction much more rapidly than schools and colleges. There are some obvious explanations. For one thing, practices can be changed more easily. For another, there are people in industry and the Services whose job it is to see that no possible improvement in teaching is overlooked, and they seem to have no counterparts in school and college administrations. But explanations of this sort have not prevented the erroneous conclusion that programmed instruction is particularly suited to industry and the Services because instruction there is of a special nature. It is said to be a matter of training rather than teaching. This is a very doubtful distinction. Training once meant nonverbal instruction, as with the use of training devices, but this is no longer true. Industry and the Services teach many of the things taught in schools and colleges, although the terminal behavior admittedly comes in smaller packages and can be more easily specified. The traditional distinction comes down to this: when we know what we are doing, we are training; when we do not know what we are doing, we are teaching. Once we have answered our basic question and specified what we want the student to do as the result of having been taught, we can begin to teach with methods not to be distinguished from "training".

It does not follow that in doing so we shall abandon any of our goals. We must simply define them more clearly. Anything which can be specified can be programed, and an experimental analysis has much more to offer in this direction than is generally realized. It is far from a crude stimulus-response theory, and it is not committed to rote memorizing or the imparting of a monolithic, unchanging truth. It has as much to say about solving problems, inductive or deductive reasoning, and creative insights, as about facts. We have only to define these terms and a technology of teaching becomes applicable. Specification, of course, is only the first step. It is not easy to construct and test good programs, and few people have the necessary competence. But this is just the point at which educational reform should start.

Another important field of application is classroom management. The teacher who understands reinforcement and is aware of the reinforcing effects of his own behavior can control his class effectively. Those who are interested in intellectual matters have tended to leave classroom discipline to others, but at great cost. Much of the time of both student and teacher, particularly in American schools, contributes little to education. Students who are particularly hard to manage are often essentially abandoned, although there are probably a few geniuses among them.

It is here that the transition from older aversive practices is most conspicuous. Many educational reformers -- Admiral Rickover among them, for example -- look with envy on the disciplined classroom of European schools. It appears to be a background against which the student should use his time most profitably. But punitive teahniques have objectionable by-products, and we are led to explore the possibility of creating an equally favorable background in other ways. It is a particularly difficult problem because we must create instructional contingencies which compete successfully with contingencies involving sex, aggression, competition, and other powerful aspects of the student's daily life. To often the good student is simply one who is unsuccessful in other ways. He responds to instructional contingencies because he has not come under the control of others. That is, of course, poor selection. We need to recruit scientists who could be successful in any walk of life. But we are not likely to find them until we take the design of classroom behavior seriously.

Effective instructional contingencies which generate the behavior we want are more difficult to arrange than those in programmed instruction. Special skills on the part of the teacher are needed, not only in maintaining discipline but in teaching the kinds of nonverbal behavior which figure so prominently in special fields, such as laboratory experimentation. The teacher must become a kind of behavioral engineer. Curiously enough, the nature of the enterprise is clearest with respect to an even more difficult problem. Institutions for the care of autistic or retarded children and training schools for serious juvenile delinquents have begun to make effective use of operant conditioning. Because of either their heredity or their early environments, certain kinds of people do not respond well to normal contingencées of reinforcement. A special environment must therefore be constructed. Ogden R. Linsley has called it a prosthetic environment. Eyeglasses and hearing aids are prosthetic devices which compensate for defective sense organs, as crutches and artificial limbs compensate for defective organs of response. A prosthetic environment compensates for a defective sensitivity to contingencies of reinforcement. As one feature, the status of reinforcers is clarified. In many institutions tokens are used which are exchangeable for sweets or privileges, and they are made contingent on behavior in ways which make them effective reinforcers. Many of these defective organisms will aways require a prosthetic environment, but others may be brought under the control of the normal reinforcers in daily life, such as personal approval or the successful manipulation of the physical environment.

Contrived reinforcers intended to have a similar effect are by no means new in education. Marks, grades, diplomas, honors, and prizes, not to mention the teacher's personal approval, are not natural consequences of the student's behavior. They are used on the assumption that natural consequences are not enough to induce the student to learn. Several objections may be leveled against them. In the first place, they are conditioned reinforcers which are likely to lose their power. This is even true of personal reinforcers if they are not genuine. When our telephone says to us, "I'm sorry. Your call did not go through," we may respond at first to the "I'm sorry" as if it were spoken, say, by a friend. Eventually, we ask "Who is sorry?" and look forward to the day when machines will be permitted to behave like machines. The computers use in computer-aided instruction are particularly likely to "get personal". They call the young student by name (after he has told them what it is) and type out exclamations of delight at his progress. But the natural reinforcers which made these expressions reinforcing in the first place do not follow. What is not so obvious is that personal approval in the classroom may be equally spurious. George Bernard Shaw is responsible for a principle which may be stated in this way: never strike a child except in anger. A complementary

principle in the classroom is this: never admire a student except when he is behaving admirably.

But the objection to grades, prizes, and synthetic personal approval is not that they are contrived, but that the contingencies in which they are used are bad. An experimental analysis is most valuable at just this point. To bring a class under control, the teacher must begin by making the reinforcers available to him explicitly contingent on the behavior he wants. Some students may need contingencies as conspicuous as those used with autistic children or juvenile delinquents. Money is a system of token reinforcers which should not be ruled out of account. (It could solve the high school dropout problem if contingencies were right.) But once a classroom is under control, a teacher must move to more subtle contingencies and eventually to those inherent in the everyday social and physical environment of the student.

Techniques of reinforcement are available which can replace the aversive techniques which have dominated education for thousands of years. We can have students who pay attention not because they are afraid of the consequences if they do not, or because they are attracted by fascinating if often meretricious features, but because paying attention has proved to be worthwhile. We can have students who are interested in their work not because work has been chosen which is interesting or because its relation to naturally interesting things has been stressed, but because the complex behavior we call taking an interest has been abundantly reinforced. We can have students who learn not because they will be punished for not knowing, but just because they have been successful or because they have begun to feel the natural advantages of competence over ignorance. We can have students who will continue to behave effectively after instruction has ceased because the contingencies which have been used in instruction have their counterparts in daily life.

Above all, we can have dedicated students who become dedicated men and women. Many interesting aspects of human behavior, often attributed to "motivation", are the results of various schedules of reinforcement. Although these have been extensively analysed, almost no attention has been given to them in educational theory. A common criticism of programmed instruction, for example, is that frequent reinforcement leaves the student unprepared for a world in which reinforcers may be scarce, and this would be true if no attention were paid to the problem. But programming techniques are available which permit us to sustain the behavior of the student even when reinforcers are very rare indeed. One of the most powerful schedules -- the so-called variable-ratio schedule -- is characteristic of all gambling systems. The gambler cannot say that the next play will win, but a certain mean ratio of wins to plays is maintained by the system. A high ratio will not work when it is encountered for the first time because the player will "extinguish" during a long run before a win, but a low ratio will be effective, and it can be "stretched" as the behavior permits. This is the way a dishonest gambler hooks his victim. He begins by permitting the victim to win fairly often, but as the probability of continuing to play increases, the ratio is increased. Eventually a high level of activity is reached during which the victim will continue to play without winning at all. The power of the schedule is most obvious when it produces a pathological gambler, but pigeons, rats, monkeys, and other lowly organisms have become pathological gamblers on the same schedule.

And so have scientists. The prospector, the explorer, the investigator, the experimenter -- all meet with success on a variable-ratio schedule. The dedicated scientist continues to work even though the ratio of responses to reinforcers is very high, but no one would become a dedicated scientist if he started at a high value. He must start with a smaller ratio. It would not

be correct to say that we know how to arrange a program which would always lead to a high ratio, but at least we know the kind of schedule needed. In any case, the extraordinary effects of the scheduling of reinforcement should be kept in mind. In designing a laboratory course, for example, we should keep an eye on the student's successes and on the way in which they are spaced out. We then increase the chances that we shall produce students who not only know how to conduct experiments, but show an uncontrollable enthusiasm for doing so.

The new materials which have been made available for teaching science in high school are genuinely exciting. Nevertheless, instruction itself is still not far from traditional practices. The very forces which have made these practices traditional make them easy to teach. The relations demanded between teachers and students are characteristic of daily life and arouse no anxiety. The methods can be justified to parents, policy makers, supporters of education, and the students themselves. They call for no extensive changes in administration. And of course, they have their occasional successes -- particularly with good students or in the hands of good teachers. All this favors the status quo. It is only when we look at the remote consequences that we begin to ask questions. One consequence we can no longer refuse to face is the fact that we are not recruiting and training the scientists we need.

Any radical change in practice must overcome severe disadvantages. We do not yet have all the new practices we need. Much more is known about the basic processes of learning and teaching than is generally realized, but it has not yet been put to work, and we no doubt need to know much more. Technological uses have also not been fully explored. The design and construction of both methods and materials is a difficult enterprise, and it demands a kind of specialist who is, at the moment, in short supply. And when, at last, we have devised effective methods, we must convince others that they should be used. Extensive administrative changes must be made. (The changes needed simply to permit the individual student to progress at his own rate are prodigious.) Teachers need to be trained. A common complaint when new materials do not work is that the teachers are incompetent. This is not only unfair, it shows a failure to recognize the point at which the improvement of teaching should begin. Materials are well-designed only if they can be used by available teachers. Teachers can profit from an improved understanding of behavioral processes, but they need more than a few new principles. Very substantial changes in classroom practice must be made.

A genuine improvement in teaching science is, in short, difficult -- possibly as difficult, say, as the Bomb. Yet there is no more important problem facing America today, because its solution bears directly on the solution of all our other problems. It is the sort of challenge scientists are accustomed to accept. They, above all others, should appreciate the need to define objectives -- to know, in this instance, what it means to teach science. They should be most likely to recognize the weaknesses and dangers in casual experience and in folk wisdom based on that experience. They, above all others, should know that no enterprise can improve itself to the greatest possible extent without an intensive analysis of its basic processes. They should be best able to gage the importance of science in the immediate and distant future, and should therefore most clearly realize the extent of the disaster which will follow if we fail to recruit for science a large segment of our most intelligent and dedicated men and women. It is no time for half-hearted experiments. The improvement of science teaching calls for the most powerful methods which science itself has to offer.

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