Teaching Science in High School—What Is Wrong?

Scientists have not brought the methods of science to bear on the improvement of instruction.

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The scientific community faces a serious problem. Science and technology are growing at an ever-increasing rate, but the number of young men and women going into science is not keeping pace. Only a fairly small percentage of high school students go 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 becomes more and more dependent on science as the years pass.

A possible explanation is that the life of the scientist has lost some of its glamour. It may offer less chance for individual achievement, and its exciting moments may be reserved only for those who have had a very extensive preparation. Even so, the main fault must lie with education. Good teaching should give an accurate account of what science is and does, of what a single scientist may contribute to the world, and of the genuine excitement of those who enjoy science for what it is—the great art of the 20th century. Above all, education should recruit the scientists of the future, finding the right people, giving them the knowledge and skills they need, and providing the satisfactions which will make them creative and dedicated men and women. Only if it does so can we hope to find those who will practice science in our universities and in industrial and governmental laboratories, and who will teach science in our schools and colleges to keep the enterprise going. Only effective teaching will create that large pool from which, in each generation, a few great scientists are drawn.

The problem has not gone unnoticed. For the past 10 or 15 years education as a whole has been sharply criticized, and many 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 a chance, selecting them impartially, supporting them financially, and removing social and racial barriers. We need more and better capital equipment—texts, workbooks, films, and audiovisual devices, including teaching machines and television. We need to change our curricula, making a sensible selection among the things to be taught and bringing what is taught up-to-date.

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, particularly physics, has not turned sharply upward. Possibly it is too soon to expect results. Educational practices change slowly, and we may yet see progress. But some possible reasons why improvement has not been more dramatic may 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. No suggestion is made that we should learn more about what is happening when a teacher teaches and a student learns. On the contrary, the issue is avoided in almost all current proposals for the improvement of education. Pedagogy is a dirty word, and courses in "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. 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 no longer actively promote pedagogy or method as formalized practice. Instead, 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 as they themselves have been taught, as they have seen others teach, or as experience dictates.

Classroom Experience

What is learned from classroom experience is perhaps likely to be more useful than formalized rules and prescriptions, but the classroom is nevertheless 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. 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 analyzed and can seldom be communicated. In the hands of a good teacher a new text, a new set of materials, or a new method may be dramatically successful, but it does not follow that it will be successful in the hands

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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, and they learn without being taught or even when taught by a bad teacher. But 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 work together in harmony and the students obviously learn 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 these examples are 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 analyzed or can be communicated. We cannot improve education to any great extent by finding more good teachers and more good students. We need to find practices which permit all teachers to teach well and under which all students learn as efficiently as their talents permit.

A first step is to recognize how misleading classroom experience is as a source of educational wisdom. Its outstanding defect is that the teacher seldom sees the effects of what he has done. The significant results of teaching lie in that distant future in which students make use of what they have learned, and it is a future usually closed to the teacher. He knows nothing of what happens to most of his students. He is influenced instead only by short-term results, and many of these not only contribute nothing to long-term gains but may actually conflict with them.

The Excited Classroom

No teacher enjoys students who are disorganized, inattentive, lethargic, or resentful. But students may be lively and attentive 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 if they show that he has been teaching successfully or by wrong if he must control 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 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 then raises his hand to avoid being called on and the student who knows the answer keeps his hand down, hoping to get a chance. The class is excited, the teacher is in control, and everyone may be having a good time. But the game is quite unrelated to the subject being taught—it is the same for all subjects—and its educational value may be questioned. It may induce some students to engage in more profitable activities, but it is not characteristic of thoughtful discussion or study, and its long-term effects may be negligible or even 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.

Hand-waving may seem too trivial to mention, but the same kind of game is played with verbal interchanges. 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, he may induce his students to protest, disagree, insist, and defend themselves in a lively fashion. All this is valuable in teaching students to argue and in giving them reasons for acquiring facts to be used in an argument but, like the hand-waving game, it is unrelated to subject matter and it gives the student a wrong impression of scientific thinking. 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. The Great Conversation which has been going on for more than 2000 years has not been notably productive of useful information or wisdom. To suggest to high school students that science is a kind of running debate is to risk selecting potential debaters rather than potential scientists.

Both teacher and student can be similarly misled by practices designed primarily to make science interesting. Students who take an interest in things are likely to learn something about them, and making a subject interesting is no doubt worthwhile, but it is a mistake to confuse arousing interest with teaching. In a recent review of a book on the mathematics 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 do we hear 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 materials and techniques designed to generate interest may conflict with good teaching.

Attention

A student who is not paying attention is obviously not learning, and the teacher is therefore reinforced when he behaves in ways which attract attention. Audiovisual materials, texts with colored pictures and charts, animated films, and demonstration experiments full of surprises are often used for this reason. 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 for the student to discover that interesting things happen when he 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, and who watch films and demonstrations which seem no more interesting than nature itself, until close observation shows how fascinating they really are. Materials miscarry in the same way when they are designed to appeal to a student's interests outside the classroom—the physics of the tennis court, the chemistry of the kitchen. 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 doing or that interesting aspects of a subject should not be pointed out, but in relying too heavily on the attractions of science we give the student a wrong impression of what he is to find when he pursues science further, and we should not be surprised that he drops out when he discovers the actual state of affairs. The things which commit the mature scientist to a lifetime of dedicated research are not the kinds of 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 dedication can be instilled in the student, as we shall see, but not by making a subject interesting.

Discovery

Another practice which has the effect of immediately rewarding the teacher even though the ultimate consequences are questionable is letting the student discover science for himself. This was the great principle which Rousseau developed in his book *Émile*. Let the student learn from nature, not from what others have said about nature. Let him go directly to the facts, to *things*, which alone are incorruptible. The principle 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. The principle seems particularly appropriate in teaching science where the great achievements take the form of discoveries. The scientist works in order to discover, and he continues to work so long as he has a chance to discover. Why should the student not 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—either in the form of books, charts, tables, and so on, or in the form of behavior taught to new members of a culture. Education is charged with the transmission of knowledge in the second sense, 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. We raise a serious obstacle to teaching 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 for rediscovery are questions concerning the available time and energy of teachers and students. The answers must take into account the efficiency of teaching methods.

The problem is 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 can change as occasion demands. It is no solution to this problem to let the student discover things for himself, because what he discovers will also soon be out-of-date.

Of course we want to encourage students to inquire, explore, and discover things, and we want to teach them to do so efficiently. We must teach a wide range of scientific methods as well as facts. Many of the verbal practices of science have been carefully formulated by mathematicians, logicians, statisticians, and others, and they are usually part of a science curriculum. The nonverbal day-to-day behavior of the scientist in his laboratory has in contrast 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 *are* taught well by that method. The guided discoveries of the classroom bear only a vague resemblance to genuine scientific discoveries. The archetypal pattern of this kind of teaching is the scene in Plato's *Meno* in which Socrates leads the slave boy through Pythagoras' 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 had finished 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 discovery of the theorem. Polya (*3*) has published a delightful account of how one might tease out the formula for the diagonal of a parallelepiped from a class of high school students, but the hints, suggestions, corrections, and heuristic exhortations he uses 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, which may sustain them in further work. Even so, they are not necessarily then more likely to make other discoveries by themselves, and 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 necessarily a rare event and cannot explain the quality or nature of most of his behavior.

Aversive Control

These, then, are a few examples of classroom practices which flourish because their immediate effects are reinforcing to students and teachers in spite of the fact that long-term effects may be weak, lacking, or actually undesirable. There are no doubt other reasons why the practices flourish. Education is in 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, in which students study primarily to avoid punishment and which 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, which are the commonest products of such a system. 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 practices may be—for teacher and student alike—the fact remains that they are not really effective alternatives. The proof is that the teacher is forced back again and again upon the old coercive pattern. In spite of all our efforts, it is still true that students learn mainly to avoid the consequences of not learning. The commonest practice in high school as well as college is still "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 upon his failure. In doing so we may give him some reason to learn, but we do not teach.

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, of course, only of methods which have actually been tried, but it tends to be used as an argument against trying new ones. It is not only a confession of failure but a form of exculpation. By admitting that we cannot teach, we avoid confessing that we have failed to do so, and we 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, and the present state of education is proof that we have not yet been successful.

What Does Teaching Mean?

An important first step in searching for better ways of teaching is to define our terms. What is happening when a student learns? Traditional theories of education almost always answer that question in mentalistic ways. The student is said to begin with a desire to learn, 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 quickly retrieved when needed. 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 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 really explain nothing. Their most serious shortcoming is that they do not tell the teacher what to do in order to bring about changes in his students or give him any satisfactory way of knowing whether he has done so. If these are indeed the tasks of the teacher, we must agree that he cannot really teach. It is even doubtful whether he can help the student learn.

A much more promising approach is to look at the student's behavior—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 the 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 will actually learn.) 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 *does* 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. Scientific thinking is an extraordinarily difficult field, and we have not advanced very far in analyzing it, possibly 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 a science, a grasp of its structure, an understanding of its basic relations, we shall be endlessly admired. If, instead, we specify the things we want him to *do,* verbally and nonverbally, we risk being called mechanical and shallow, even though the things we list are precisely the things from which an understanding or grasp of the structure of the science is inferred. 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.

Programmed Instruction

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 our students are 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 gaps, making sure the student understands one step before moving on to another, and thus, incidentally, making sure that he is frequently successful. All these things are done in constructing a good program, but the central point has still not been reached.

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 so far as we know, there is only one way of doing so. Behavior is strengthened when it is followed by certain kinds of consequences. To be more precise, a response which produces a so-called positive reinforcer or terminates a negative is more likely to occur again under similar circumstances. We use this principle of "operant conditioning" to strengthen behavior by arranging reinforcing consequences —by making available reinforcers contingent on behavior. This is often said to be nothing more than reward and punishment, and there is certainly a connection. But the traditional concepts of reward and punishment are about as close to operant conditioning as traditional concepts of heat, space, or matter are to contemporary scientific treatments. Only a detailed experimental analysis of contingencies of reinforcement will supply the principles we need in the design of effective instructional practices.

Teaching is 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 appear. Programmed instruction is designed to solve a special problem. We cannot simply wait for our student to behave in a given way, particularly in the complex ways characteristic of a scientist, in order to reinforce him. Somehow or other we must get him to behave. Our culture has devised relevant techniques for other than educational purposes. We resort to verbal instruction, for example, when we simply tell the student what to do, or we show him what to do and let him imitate us. If we induce the student to engage in terminal behavior in that way, however, he will be much too dependent upon being shown or told. He will not have learned. We begin instead with whatever behavior the student has available—with behavior which does not call for much help. We selectively reinforce any part which contributes to the terminal pattern or makes it more likely that the student will behave in other ways which contribute to it. The devices we use to evoke the behavior can then be easily withdrawn, so that the terminal behavior appears upon appropriate occasions without help. A high degree of technical knowledge is needed to do this.

Many instructional programs have been written by those who do not understand the basic principle, 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 proficient in a field because he cannot easily appreciate its effect on a new learner. Anyone who wants to get the feel of programmed instruction should try his hand at a good program in an unfamiliar subject. A colleague whose work had begun to move in the direction of biochemistry worked through an excellent program in that field. "In 3 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 reasons. For one thing, teaching techniques in these organizations can be easily changed. For another, there are people in industry and the Armed Services whose job it is to see that no possible improvement in teaching is overlooked. Unfortunately they have no counterparts in school and college administrations. Explanations of this sort have not prevented the erroneous conclusion that there is another reason why instruction is particularly suited to industry and the Services. Instruction there is said to be of a special nature, a matter of training rather than teaching. This is a very dubious distinction. Training once meant nonverbal instruction, usually through the use of training devices, but that 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. The important thing is that it 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 taken the important first step and specified what we want the student to do as the result of having been taught, we can begin to teach in ways with respect to which this outworn distinction is meaningless.

In doing so we need not abandon any of our goals. We must simply define them. Any behavior which can be specified can be programmed. 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 is not committed to rote memorizing or the imparting of monolithic, unchanging truth. It has as much to say about solving problems, inductive or deductive reasoning, and creative insight as about learning facts. We have only to define these terms and a technology of teaching becomes applicable. Specification, of course, is only the first step. Good programs must be constructed. At the moment only a few people have the necessary competence, but this is one of the points at which educational reform should start. Scientists, as subject matter specialists, must play a major role.

Classroom Management

Another important application is in classroom management. The teacher who understands reinforcement and is aware of the reinforcing effects of his own behavior can control his class. Those who are interested in the intellectual side of education have tended to neglect classroom discipline, but at great cost. Much of the time of both student and teacher is now spent in ways which contribute little to education. Students who are particularly hard to manage are often in effect abandoned, although there are probably 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 uses his time most profitably. But punitive techniques have objectionable by-products, and we are led to explore the possibility of creating an equally favorable background in other ways. 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 such fields as laboratory experimentation. It is a particularly difficult problem because we must compete with other contingencies in the student's daily life involving sex, aggression, competitive sports, and so on. Too often the good student is simply one who is unsuccessful in other ways. He responds to our instructional contingencies only because he has not come under the control of others. The result, of course, is poor selection. We need to recruit scientists from those who could be successful in any walk of life. To do so we must take the design of classroom behavior seriously.

Effective instructional contingencies in the classroom are more difficult to arrange than those in programmed instruction. Curiously enough, the nature of the enterprise is clearest with respect to a more difficult kind of student. Institutions for the care of autistic or retarded children and training schools for juvenile delinquents have begun to make effective use of operant conditioning. Because of either their heredity or their early environments, certain people do not respond well to normal contingencies of reinforcement. A special environment must be constructed. Ogden R. Lindsley 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. In such an environment reinforcers may be clarified; many institutions reinforce students with tokens, exchangeable for other reinforcers such as sweets or privileges, which can be made contingent on behavior in conspicuous ways. Many of these defective people will always require a prosthetic environment, but others can be brought under the control of the reinforcers in daily life, such as personal approval or the successful manipulation of the physical environment, and can thus be prepared for life outside an institution.

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 seldom the natural consequences of the student's behavior. They are used on the assumption that natural consequences will not induce the student to learn. Several objections may be leveled against them. In the first place, as conditioned reinforcers they 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. The number you have reached is not in service at this time," we may respond at first to the "I'm sorry" as if it were spoken, say, by a friend. Eventually, we may stop to ask, "*Who* is sorry?" and look forward to the day when machines will be permitted to behave like machines. The computers used in computer-aided instruction are particularly likely to "get personal" in this way. They call the young student by name and type out exclamations of delight at his progress. But the natural consequences which made these expressions reinforcing in the first place are not forthcoming, and the effects extinguish. What is not so obvious is that personal approval 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. Contrived admiration is self-defeating.

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 available reinforcers explicitly contingent on the desired behavior. Some students may need reinforcers as conspicuous as tokens or points exchangeable for goods or privileges. Money is a token reinforcer which should not be ruled out of account. (It could solve the high school dropout problem if the contingencies were right.) But once a classroom has been brought under control, a teacher must move to more subtle contingencies and eventually to those inherent in the everyday physical and social environment of the student.

Techniques of reinforcement are now 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 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 learning, but because they have begun to feel the natural advantages of knowledge over ignorance. We can have students who will continue to behave effectively after instruction has ceased because the contingencies which have been used by their teachers find counterparts in daily life.

Above all, we can have dedicated students who will become dedicated men and women. Many interesting aspects of human behavior, often attributed to something called motivation, are the results of various schedules of reinforcement (*3*) to which almost no attention has been given 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 the possibility were neglected. 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 be sure the next play will win, but a certain mean ratio of plays to wins is maintained by the system. A high ratio will not take control if it is encountered without preparation, because any available behavior will extinguish during a long run, but a low ratio will be effective and can be "stretched" as the behavior builds up. This is the way a dishonest gambler hooks his victim. At first the victim is permitted to win fairly often, but as the probability that he will continue to play increases, the ratio is increased. Eventually he continues to play when he is not 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 reinforcement is very high, but he would not have become a dedicated scientist if he had started at that ratio. It would not be correct to say that we can always arrange a program which starts with frequent successes and leads inevitably to a high ratio, but at least we know the kind of schedule needed. In any case, the extraordinary effects of scheduled reinforcements should not be overlooked. In designing a laboratory course, for example, if we keep an eye on the student's successes and particularly on the way in which they are spaced, we are more likely to produce a student who not only knows how to conduct experiments but shows an uncontrollable enthusiasm for doing so.

The new materials which have been made available for teaching science in high school are genuinely exciting, but the fact remains that classroom practice has not really changed very much. The forces which make practices traditional make them easy to transmit to new teachers. The relations between student and teachers demanded by such practices arouse no anxiety. The practices can be justified to parents, policy-makers, supporters of education, and 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*.

The change which is needed must overcome many handicaps. Much more is known about the basic processes of learning and teaching than is generally realized, but we need to know still more. What is known has not yet been put to use very effectively. The design and construction of methods and materials is a difficult enterprise which demands a kind of specialist who is, at the moment, in short supply. New practices need to be thoroughly tested. And when, at last, we have devised more effective methods, we must convince educators that they should be used. Extensive administrative changes must be made. (The changes required simply to permit the individual student to progress at his own rate are prodigious.) Teachers need to be retrained as skillful behavioral engineers. The common complaint that new materials do not work because the teachers are incompetent is not only unfair, it shows a failure to recognize another point at which the improvement of teaching might begin. Materials are good only if they can be used by available teachers. It is quite possible that materials can be designed which will permit teachers to teach well even in fields in which they have no special competence.

The Improvement of Teaching

Scientists are wary of being asked about their "values." They hesitate to speak of progress because they are likely to be asked, "Progress toward what?" They are uneasy in suggesting improvements. "Improvements in what sense?" The current fashion is to speak only of educational *innovation.* All that is claimed for a new practice is that it is new. We need a much more positive attitude. The efficiency of current methods of teaching is deplorably low. The change which occurs in a student as the result of spending one day in high school is discouragingly small. We need to improve education in the simple sense of making it possible to teach more in the same time and with the same effort on the part of teacher and student. It is a difficult assignment—possibly as difficult, say, as the control of population or resolving the threat of nuclear war, but there is no more important problem facing America today because its solution will advance all other solutions.

It is the sort of challenge that 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 quick to recognize the weaknesses of casual experience and of folk wisdom based on that experience. They, above all others, should know that no enterprise can improve itself to any great extent without analyzing its basic processes. They should be best able to gage the importance of science in the immediate and distant future and therefore the extent of the disaster which will follow if we fail to recruit for science large numbers of our most intelligent and dedicated men and women. It is no time for halfhearted measures. The improvement of teaching calls for the most powerful methods which science has to offer.

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4. This article was prepared with the help of NIMH grant K6-MH-21,775-01.

The Experimental City

With components designed as an experimental system, new cities in open land will open up land in old cities.

Athelstan Spilhaus

A federal commissioner recently expressed an opinion typical of the "hopelessness approach" to city problems when he said, "We cannot, even if we would, dismantle the urban complex." I disagree completely. The overgrown urban complex must be selectively dismantled and dispersed if we are to cure the ills of the megalopolis.

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Half of the people in the United States live on 1 percent of the land, and there is a continual drift to the big cities. Urban renewal encourages the increase in the size of the cities. Two- or three-story slum buildings are torn down, and sterile, high-rise, so-called low-cost housing brings more people into the center of the city than ever before, compounding the problem.

Secretary of the Interior Stewart Udall, in an article which appeared in the September 1967 issue of the *Saturday Review,* addressed himself to the fundamental problem, that of controlling the population, and took a stand that must be considered courageous for a man in his position. If we consider that *any* excess that is harmful to decent living is a pollutant, then the prime pollutant on earth is too many people. But until we have the sense to control population, something has to be done for all these people, and here I discuss the question of what is to be done.

In his article, Udall goes on to say:

> Our annual population growth of 4,000,000 people increases the physical and social pressures, causes us to seek quick remedies, leads us to waste too much wealth on quick-fix projects that provide at best a temporary respite from yesterday's mistakes. The razing of tenements, their instant replacement by high-rise slums, changes the facade—not the features—of the ghetto.

I agree completely, and propose, as a corrective, development of a system of dispersed cities of controlled size, differing in many respects from conventional cities, and surrounded by ample areas of open land. The proposed Minnesota Experimental City will be a prototype.

The initial group that planned the Experimental City project in Minnesota