fundamental. Our verbal and musical symbols scarcely represent the whole field of possible sounds; painting, sculpture and architecture scarcely scratch the surface of the organization of visual space; and I am not sure that mathematical symbols represent all the forms of biological logic. What new kinds of symbols are we preparing to manipulate, color organs, Labanotation for the ballet, or a dozen others, calling for new talents and developing new types of youthful genius?

But whether brilliance in these arts will be inherited or only acquired by the children, the colonies and concentrations of specialists may be taking the human race branching into new directions. As geographical isolation breaks down, the great historical races of man, with their so-obvious external animal differences of noses and skin, are amalgamating on a hundred fronts. The internal differences, however, the differences of sheer intellect and of various kinds of abstract creativity, may be diverging into new races of mind, all Newtons, Beethovens, and Michelangelos, as far removed from what we have called normal as what we have called normal is removed from the gorilla.

What symphonies they will compose! What laws they will discover! What centuries lie ahead!

7. THE ART OF CREATIVE THINKING

THE FACTORS in creative intellectual work have been discussed for thousands of years. Everyone is interested in the question whether, by taking thought, he can add some cubits unto his intellectual stature. It does not seem so impossible now as it once did. Whole populations now increase in physical height — certainly a less variable characteristic than the intellectual powers — by one or two inches in every generation, presumably as a result of better nutrition and control of disease; and no one can say how far up we may shoot.

Perhaps we have also been intellectual dwarfs deprived of important growth factors until now. Such factors as personal attention are said to raise the I.Q.'s of orphans, and tutoring is believed to raise those of ten-year-olds in England about to take their pre-university examinations. The average American is said to be about ten points higher on the old intelligence tests than a generation ago. Small fry now know the days of the week and the months of the year almost a year younger than they did then. This is probably not due to any increase in mental agility, but just to the enrichment of the children's culture, from the child-oriented parents to the TV set. Yet it represents a measurable increase in our collective mental altitude.

This all suggests that a single individual, even an adult, might also be able to make considerable increases in his

in harmony with itself. To develop the very greatest powers, the forty days in the wilderness may be a creative necessity. But I think we need not get into such deep questions of personal integration here. Most of us would be more harmed than helped by such self-probing, like the centipede who tried to remember which leg moved after which and lay distracted in the ditch, considering how to run. It is probably best for a brilliant youngster to practice his creative powers for some years and get firmly in the habit of them before he begins to question them too much.

The aim here is simply to show as objectively as possible that creative success, or problem-solving in the widest sense of the term, can be factored into three or four basic elements about as cleanly as, say, mountain-climbing, which is a close physical analogue of the intellectual process. We can identify what the chemist might call the "rate-determining steps" in the analytical process. And the successive steps can be made easy and enjoyable and habitual by perfectly straightforward biological feedbacks and indirect motivational devices.

Much of what I have to say about mental work will be simply what every thinking man formulates for himself in one language or another — if he stops and thinks! But some of the working methods to which I want to call attention seem to have an effectiveness which has been little appreciated, at least by scientists. The indications here are that if scientists and psychologists applied to the intensifying of creative work what we now know about feedback and amplification effects, still better methods might be found; and the wider use of such work schemes might lead to a tremendous increase of powers for the whole intellectual community, a considerable advantage to any group

or nation that first discovered how to bring it about.

Let us look at the framework of the intellectual problem-solving processes, the operational factors that go into a successful result. Several of the factors in intellectual accomplishment show up clearly when we consider the differences in different children. We suspect first that there is a genetic factor. In the cradle, one infant is far more alert and inquisitive than another. It also seems to be pretty well established that genius does tend to run in families, in spite of counter examples such as the undistinguished parentage of Leonardo, Newton, and Shakespeare.

But the development of civilized intellectual powers requires two more things. First, that the child be presented with civilized problems; and second, that he be given civilized symbolic apparatus or so-called conventional signs to handle these problems. We all know the value of symbols in increasing mental clarity and power. Musical prodigies come from musical homes where they have learned the notes. A wild mathematical genius would have to spend a lifetime creating his own number system if he had been taught no words for the numbers beyond two. A Basuto child is handicapped in learning chemistry if he has no reading or writing or arithmetic until his teens. This is what public education is for, to create a population that can communicate and solve problems that most of us would never solve by the capricious development of our innate talents. What unguessed kinds of symbolic apparatus still lie beyond us, that might be taking our children just as much farther again?

In addition, as some psychologists now emphasize, early environmental stimulation — the presentation of challenging problems — may be a major factor in developing a child's intelligence. Brilliance in school frequently follows

upon early enrichment in the home. It may be that many of our children — not all, but the brightest — are kept as much below their potentialities as the Basuto child by having no reading or writing or arithmetic until they are six. What an average child can do at six, a 180 I.Q. can do at three. Or is it that the one who does it at three is thereby lifted closer to the 180 I.Q.? No one knows. But there seems to be a strong possibility that we might greatly increase the numbers of our brilliant men if more mothers would start step-by-step educational stimulation and challenge at the cradle or just beyond.

I think the same factors — native ability, challenge and symbolic apparatus — are still important in adults, but adults have learned to ignore most challenges, and their success in responding to a problem depends on the attention and time they give to it. Another factor also enters their problems, namely, complexity; and success often depends on the skill with which a complex problem can be broken up. We are thus led to the following components in adult intellectual achievement:

	In Problem-Solving	*In Mountain-Climbing*
1.	Intellectual or creative ability	Physique and skill
2.	Time spent per day in formal application	Time spent climbing
3.	Symbolic apparatus	Feet, ropes, ladders, cable cars
4.	Skill of breakdown of problem into short sure steps	Analysis of feasible paths to the top. Rules for steps

Opposite each intellectual factor I have indicated its equivalent in physical problem-solving such as mountain-climbing. The parallel with this more familiar and more

objective discipline reassures us that we are distinguishing the factors correctly and have not omitted any. It may help to prevent such errors as the all too common one of confusing intellectual ability with intellectual level.

INTELLECTUAL ABILITY

Most of us will believe that there is some basic intellectual ability, some moment-by-moment power of the reasoning or creative machine, that is fundamental to adult intellectual success. Our discussion of it can be brief, since any such factor cannot be much subject to conscious control. Possibly we are born with minds destined to have a certain speed of operation and a certain skill in analogy and extrapolation at a certain age. Possibly we improve these qualities somewhat with practice. But at eight o'clock on Thursday morning I cannot, by taking thought, add one cubit to my stature or one kilowatt to the mental horsepower with which I do my work that day.

Nevertheless the subject should not be dropped without mentioning the physiological effects which give us an indirect control, and which people should take far more account of in intellectual activity than they do. Drugs, for example, can affect an intellectual race as well as a horse race. Whether they have a beneficial effect on the creative abilities that is not outweighed by their side effects is a question still debated with more heat than information and one that each person must decide for himself. Artists, writers, and some statesmen aid their mental powers with alcohol, students and truckdrivers use benzedrine, all Americans use caffeine, and more and more creative people are using the milder modern tranquilizers and energizers.

Some achieve remarkable results by alternating the stages of uninhibited creation, properly titrated with stages of sober critical judgment to correct the excesses. Certain trace necessities such as Vitamin A, Vitamin C, and nicotinic acid are also said to put the machinery into high gear and are easy enough for anyone to try without misgivings. Many of the differences in personal force and mental quickness between different people may be due to natural biochemical differences in the level of such trace materials.

Mental abilities also change, like athletic abilities, with sleep and diet and time of day, differently for each person. Probably these changes are related to the brain's well-known sensitivity to oxygen, carbon dioxide, and blood sugar levels. Is this why several prominent mathematical physicists have been compulsive eaters of sweets? The old scholarly phrases, the odor of the lamp, the midnight oil, the smoke-filled study — are they intellectual chemistry as well as metaphor? I mention such speculations here only to suggest how much we have yet to learn about the biochemical conditions for intellectual work. A little money spent on intelligent research on these questions — perhaps using matched chess players as subjects — might pay off handsomely. I see no reason to doubt that the right vitamins and hormones and other drugs will eventually be found to make at least as much difference to our peak intellectual health and performance as they do to our peak physical health and performance.

THE MEASURE OF ANALYTICAL THOUGHT

The other three factors in intellectual achievement are subject to more conscious control. Consider factor two. How

much time did you spend today in formal application of your intellectual powers, or more precisely, in analytical thought? Don't try to get out of it by asking me to define analytical, or by saying that every thought is analytical. You know, and I know, the difference between reading the paper or cleaning house or sitting in a discussion or writing letters or even giving lectures, and *thinking*. Analytical thinking is Sherlock Holmes thinking, figuring out from small clues the height of the criminal and whether he was left-handed. Have you made any large inference today from close observation? It does not require civilization. The successful tracker or hunter must think like this. It does not require mathematics. It can be found in the better organization of housekeeping, or in the artist's consideration of another way to represent a shadow. Any consecutive thought about what you do, why you do it that way, what would happen if you did it slightly differently, is analytical reasoning.

I would like to suggest the convenience of having a rough unit of analytical reasoning so that we can talk more or less quantitatively about how much thinking is involved in this job or that. I think a good unit would be the amount of reasoning involved in a forty-move game of chess or a hard end-game problem, or a fairly hard (for you) crossword puzzle; that is, half an hour to an hour of problem-solving. This might be called "one gamesworth" of reasoning, to give it an obvious name. It is a useful unit because we are all acquainted with such problems and have a feeling for their difficulty — easily distinguished from ten-minute problems on the one hand and from three-hour problems on the other. I also think the sequence of mental operations is fairly typical of formal thinking on complex

problems, a mixture of memory, rules of procedure, deductions, analogies, inductions, evaluations and insight, all leading to an elegant and novel solution with the loose ends tied up. Also we shall see that it is a natural unit, measuring roughly the amount of reasoning most of us can do at one sitting.

Many of us do crossword puzzles every day, but I think that few do a gamesworth of serious reasoning every day. Sherlock Holmes lived for nothing else, but most people, even creative artists and scientists, are creatures of habit and only *think* occasionally. This is unfortunate. Our highest powers lie unfocused. Count that day lost whose low descending sun sees from thy mind no gamesworth of reasoning done. "There are some problems you cannot solve in a million years unless you think about them for five minutes," to quote a famous saying of the physicist M. L. Goldberger. If, one day, a hundred million adult Americans all gave one gamesworth of thought to their work, the world would tremble and mankind would never be the same again.

There is nothing impossible about applying the mind in a more or less concentrated way for a good part of every day, if you set up the conditions for it; and this is the straightforward explanation given by many prominent men for their achievements. In *Men of Mathematics*, E. T. Bell quotes Gauss: "If others would but reflect on mathematical truths as deeply and continuously as I have, they would make my discoveries." And when Newton was "asked how he had made discoveries in astronomy surpassing those of all his predecessors, Newton replied, 'By always thinking about them.'"

Sir William Osler emphasized the importance of single-

minded concentration by saying: "There are two kinds of people, skylarks, who work in the morning, and nightingales, who work late at night. And there are two rules for success in medical research: Don't get married until you are thirty-five; and be born a nightingale."

In short, avoid the two worst interruptions, Families and Other People. Every field has its folklore about the success of the nightingales. Maybe they are born so, maybe not. But much of their secret must be that they are ready to do analytical reasoning at a time of minimum external distraction, while the more conventional skylarks are trying to think at a time of maximum distraction. The seduction of the mind to think obeys the old formula for other types of seduction: Find the place and the time, and the rest will take care of itself.

Actually I believe that the time need not be very long, that no one really spends a whole working day every day in the kind of intense analysis I am talking about. In the purest mathematics there is much routine operation to be carried out; and I suspect that the chess wizard who plays all day long is dealing most of the time with familiar situations.

Probably the brain, like the rest of our physiology, is designed for maximum power output in short bursts only. The tiger sprints away, but he tires quickly and the trained horse can easily run him down. We eat for an hour, hear a lecture or a play or a concert for no more than an hour or two or three. Patience and interest flag. In some sense the brain is indeed tired. I suggest that in concentrated analytical thought, one or two gamesworth every day would be about the maximum for most of us. This much actual thought — a couple of crossword puzzles' worth — is not

so distressing to contemplate, is it? This principle is often neglected in the long hours and numerous courses of our schools.

We can confirm this rough upper limit by looking at the output of the most prolific men. Jefferson's writings fill fifty volumes, say one per adult year. Benjamin Franklin, that "printer, statesman, writer, seller of books, philosopher, civic leader, linguist, inventor (of bifocal spectacles, a harmonica, a stove, among other things), scientific experimenter, superb autobiographer, tireless correspondent and postal-system innovator," had a similar output. At their peak, Shakespeare and Shaw produced two or more plays per year. Dickens and Scott, one or two novels per year. John Dickson Carr and Simenon, today's high-speed writers of detective novels, turn out four to ten per year. Mozart produced an opus every week or two. Euler produced over a thousand pages per year, largely algorithms; his manuscripts fill a museum room and have scarcely begun to be examined. Kelvin turned out six hundred scientific papers, roughly one a month. Today the astronomers, with their numerous stars, and the chemists, with their numerous molecules — and their numerous graduate student assistants — occasionally match this rate.

For this kind of literary and semi-literary activity, the maximum rates then seem to be in the range of two hundred to one thousand pages per year, averaging steadily about one page per day, within a small factor. Much of each page is of course grammar rather than ideas, and I would guess that this output represents of the order of one or two gamesworth of chesslike reasoning per day, say thirty to one hundred moves. A man might generate ten times as much volume with a dictating machine but scarcely ten

times as much reasoning. Averaged over the years, a tightly written page is then not far from a day's work or a natural unit of reasoning, in music or mathematics or letters. A tightly written paper or opus or chapter is evidently something like a larger natural unit of organization, which might be generated in one to four weeks of consideration and absorbed in an hour. Many of the productions of the most prolific men bear a light spontaneous stamp, and one suspects that men famous for a smaller number of works have produced at comparable rates but have revised more extensively and have been more critical about what they kept. Franklin Roosevelt is supposed to have said of Churchill that he had a hundred ideas a day, four of them good; this was enough to make the difference from an ordinary man.

Some men, literary and otherwise, may try to justify a small output on the grounds of selectivity. Stephen Spender carries things to their logical conclusion when he says, "It does not matter whether genius devotes a lifetime to producing a small result if that result be immortal."

This is a stern doctrine. Evidently poets do not have to eat, as physicists do. It also provokes the observation that the actual act of creation of the small result — immortal or otherwise — does not take a lifetime at all, but frequently only a few hours, when the moment is ripe. Schubert's best songs were written in a day, Frost's best poem in an hour, the Schrödinger equation in a weekend, and the theory of evolution by Wallace in a couple of days; Darwin's life of work was but the massive buttressing of the brief immortal idea. Who knows what immortal little result you are but two hours away from: Have you done — or revised — your page of thought today?

Thought about what?, you may say. You are not a

Schubert or a Schrödinger. Thought cannot exist in a vacuum; it must have something to think about. Quite true. Lofty subjects or simple ones. Each person must start with his own problems; if nothing else, the funny or surprising regularities of the day that are the staples of chat. But I believe that the process, and the advantage, of applying one's mind more connectedly and formally is much the same whether the thinking is applied to children's tantrums or to rocketry. Write them down explicitly, the causes and effects, the interactions and implications, what would happen if you changed this or that. Could mail delivery be made more efficient here? Other communications channels? What are the pros and cons of setting up an operations research group? Can I think of a definitive experiment to check the causal chain in these correlations? Is Billy's upset due to hunger or an aggressive playmate? Where could a few of us spend $50 to beautify this street most strikingly?

Naturally thoughts are more consequential if they are on important subjects, and on subjects you know something about; and it is better if you go on with the same subject and make a record of your thoughts day after day, so that they build up into something. But trivial ideas are fun, too — the guerrilla operations of the mind — where you get some quick objective satisfying little result and success is easy to see. Whether a serious subject or a trivial one, related to your work or outside it, give it a gamesworth of thought — all the thought it needs for an important little result — and then think how you should act on the result.

From the figures on the prolific workers and from the immortal instances, I conclude that a page or a gamesworth or two of thought every day is about the maximum; and

yet that this amount is possible for everyone and even easy. We all confess it, in our enjoyment of the daily crossword puzzle. Real thinking is brief and it is fun. It has nothing to do with being a grind or a worrier or a show-off or an intense young man. But to apply this short amount of thought to our own problems and then to act on it is so rare that the man who begins to do it systematically may soon distance competitors he has barely kept up with before. Feel no inferiority. The book you write in is your own and no one is inferior there. The daily intellectual tortoise can pass many a high-speed brain that only operates when fancy strikes.

The effort itself changes a person's outlook for the better. A gamesworth of thought takes so little time that a man who has done his hour of reasoning and has had even one idea — even a small one and still buried in the notebook — feels a sense of success and freedom for the rest of the day, or night. This alters his whole attitude toward other more routine chores and toward the practical work of translating his idea into output. He has already done his real work for the day, and the lesser problems then fall into easy perspective. First things first, and the rest will be added unto you.

This pleasure and confidence is seductive, and makes it easy to go on with such a program — one of the motivational feedbacks. I think this is one of the secrets of the habitually relaxed attitude that prolific minds so often show. The brilliant British physicists and chemists with their short hours and long teas do not have to sweat and strive, because they have learned how to think formally. Somerset Maugham took the view that if he could not become rich and famous by writing until noon, he could not do it by writing all day either.

SYMBOLIC APPARATUS

The third component of intellectual prowess is the use of the best available equipment. It is the nylon tents and oxygen tanks, and the easy donkey train as far as possible, that make the difference in climbing Everest. A man should lose no opportunity to upgrade his intellectual manipulative equipment; that is, the symbolic apparatus with which he does his mental operations.

The bricklayer, with his stretched string and try-square and clumsy bricks, no matter how economical and elegant his performance of the job, is climbing on foot while the manufacturer of prefabricated panels passes him by. Maxwell's work in electricity was able to remake communications and the world because he bridged chasms with his differential equations that could never have been crossed at all by the methods, say, of Galileo's geometry. The Bushman boy may spend two gamesworth of analytical reasoning and subtle skill to track down some animal. But after he is through, he has killed one animal. The Western boy who does the same amount of mental work on the mathematical and verbal symbols of his geometry or civics lesson in high school has gone up with a cable car to conquer heights more valuable to the human race in the long run than many animals. (He might do better if he could be given the corresponding thrill of accomplishment more frequently, too.)

We have no general index for the power of our symbolic apparatus. It might be helpful if we did, but I have been unable to think of any that satisfy me even qualitatively. It would be helpful to every research director and every company to be able to estimate more accurately the power of the methods that different men are using. Sometimes the symbols of one culture can be compared with those of an-

other by comparing the power of the weapons — on a suitable logarithmic scale — that each can produce. The Toledo blade represented an empirical metallurgy manipulating symbols with more powerful implications than the technology of chipped flint arrowheads.

The power sequence of mathematical symbols is usually clear. It goes up with speed of remembrance, simplicity of rules, and breadth of application. The Romans, for example, were held back by their clumsy number system. A child today goes directly from finger-counting to Arabic notation. Before he is nine, he may be doing arithmetic that would have taxed Cicero severely. Having seen British children learning multiplication and division, I estimate that the American child is saved six months of schooling by our decimal coinage and would be saved at least six months more by the adoption of the metric system of weights and measures. When these little differences are multiplied by millions of artisans and statesmen, it makes a terrific difference to the power of the whole culture.

Today, some high school mathematics courses include the study of sets, groups, and fields, notions unknown in American education a generation ago. The speed of education of children depends only on our symbolic inventiveness. In thirty years, or a hundred, the nine-year-olds may be using symbols as far beyond ours as ours are beyond the Romans. I can easily imagine a time in ten or twenty years when transistorized desk computers are cheaper than math texts, and when students from ten to fifteen years old will spend on Boolean algebra and the logic and programming of these machines the time they now spend repetitiously and inefficiently in the complexities of long division and solution of quadratic equations. The new subjects would be not only

easier but far more powerful symbolically and far more relevant to the work of the world.

Likewise in adult operations, mathematical or not, a man is badly handicapped if his implications are limited. We must understand instances before we can understand principles, but it is wasteful to use our problem-solving mind to multiply instances indefinitely. To use finger-counting when you might be using computing machines, to debate one employee's suggestion when you should be considering whole schemes of optimization, to plan market tactics without using game theory, is operating at too low a symbolic level. It is like trying to fight a naval battle with rowboats.

In scientific work, the crucial experiment in a given field is at a different symbolic level in its implications from the noncrucial experiment, or the experiment that just uses the apparatus on hand. Pasteur's disproof of spontaneous generation was a crucial experiment. Its implication was the restructuring of a whole area of thought. Some fields are filled with men who do little but amass facts. Obviously this is necessary in the first survey studies, but it often comes to be an end in itself. One physical chemist, now in biology, says he is beginning to think we ought to pass a law against any scientist knowing more facts than he can account for. The fields of molecular biology and of nuclear physics have been so exciting in the last ten years because they are full of analytical young men who are not merely trying to measure something but to prove something, with maximum implication.

Likewise, once the experiment is chosen, the crucial points in its success — the keys to getting it to work — are at a different symbolic level from other aspects of the manipulations. When Pauling was asked why he looked

first at such a complex molecule as hemoglobin in searching for genetic effects on protein chemistry, he replied that this substance could be obtained in quantity and purified and characterized more exactly than many apparently simpler molecules. It is operational simplicity, not paper simplicity, that is the crucial point for success. The difference in the great men, the Faradays and the Pasteurs and the Emil Fischers, is this search for operational clarity — what I am calling symbolic power — which shows up, first, in their repeated accuracy in picking out the crucial experiments that prove something; and second, in their repeated *Sitzgefühl* (to use a chess term) for the crucial points, the species to use, the gimmicks, the control of side effects, that will make the experiment work most conclusively. It would seem that almost anyone could learn to look for this operational clarity, but there are few teachers, even, who understand it.

When speaking in this general way of symbolic power, I have been thinking of a symbol as an X in a statement of the form "X implies . . ." where X might be a mathematical symbol, or a field of mathematics, or a generalization, or a manipulation or an experiment. Although my meaning is general, I think it is not ambiguous. But let me rail against those pseudo scientists who do not merely amass facts as ends in themselves, but invent pseudo-physical symbols as ends in themselves, I-percentages and W-factors and so on, apparently supposing that their non-mathematical disciplines will acquire power by giving every ambiguous notion a Roman letter. Probably something with boiling oil in it is the only cure for this. A written symbol must have a well-defined operational and manipulative meaning. The introduction of supposed symbols that

have none is a scientific lie and can lead a whole generation astray.

Different symbols differ by so many orders of magnitude in their symbolic power — whether we can measure this quantitatively or not — that the man who uses powerful symbols can frequently get all the social reward he wants by an occasional bright idea and may not need to work very hard. From the company's point of view, ten minutes of thought on a problem by, let us say, Langmuir might be more valuable than eight hours or eight weeks of work by someone else. (Yes, a "consultant-fee index" to symbolic power might be possible.) The full-time employees who watch jealously the highly paid consultant flitting from here to there often realize neither how much more time he spends in formal thinking than they do nor how much more powerful his symbolic manipulations are.

Several years ago, the psychologist Roy John devised a machine that follows the reasoning of a person trying to solve a particular type of mechanical problem. He found that some persons would come back twenty times or more to pushing the same buttons in the same unsuccessful sequence, without either making a record of what they had done or stopping to think what the lack of success implied about the necessary next step. We are creatures of habit, and it is psychologically so much easier to repeat the same computations over and over "to be sure," or to debate and heckle and use gamesmanship when we should be writing down the alternatives for careful evaluation, that few of us use even one-tenth or one-hundredth of the symbolic apparatus we actually know how to manipulate, and even fewer go on to learn or invent still more effective short cuts.

If we did, whole industries would turn flip-flops.

STEPS TO THE TOP

The fourth component in adult creative success is the breaking up of big problems into a sequence of small steps. Recent experiments on learning seem to show that the elementary acts of learning do not require repetition, as had been supposed previously, but that we learn instantaneously a few small bits at each experience, a few more at the next, and so on. This is a new illustration of the general rule that mental jobs, like mechanical jobs, are done best if they are broken into small bits just the right size to manipulate easily.

In problem-solving, the bits must add up in sequence to form a path to the solution. Just as in climbing a mountain, you must think a little about the whole path in advance even though there are steps you cannot work out exactly until you get to them. You do not go up by the route you want to, but by the route you can, and often by the route you must. When you seem to be near the solution, you may still have to go back and start over a different way. Some problems can no more be solved by frontal assault than the east face of Long's Peak can be climbed straight up. Sometimes we may take an easy step, sometimes a hard step, sometimes tangential or away from the goal; but if we are to get there, every single step must be short and sure and must start from the step before.

In this sequence, both in individual problem-solving and collective problem-solving, special attention is being given today to separating clearly the stage of conjecture from the stage of criticism, so that the necessary creative conjecture will flow freely. Edward Teller has expounded the doctrine of "The Sixth Idea," saying that some problems can be

solved only by taking five impossible ideas and then finding the sixth one that, combined with them, will make the whole scheme workable. In rough country, the wheel is obviously a useless invention and so is the road, until you put them together. The Wright brothers had to invent not only the airscrew and a kind of aileron, but also the wind tunnel to optimize them in. Such multiple requirements were an almost impossible block to primitive invention up to this century; but they need not be impossible, either for technical or social inventions, when we combine conjectures systematically before criticism.

Some recent books treat particularly cogently the tactics of research and the tactics of inductive problem-solving (as distinguished from the strategy, which can still be learned only from great teachers) and they give the conditional sequence of steps in considerable operational detail. One of these books is E. Bright Wilson, Jr.'s *Introduction to Scientific Research*. Others are G. Polya's primer *How to Solve It* and his two more advanced volumes *Induction and Analogy in Mathematics* and *Patterns of Plausible Inference*, which together he calls *Mathematics and Plausible Reasoning*. Wilson's whole point is that skill in research can be taught. Polya's point — by no means limited to mathematics! — is that skill in inductive inference can be taught, almost as well as the old Greek skill in deductive inference. I am fond of telling my students that *How to Solve It* will increase their scientific prowess by a factor of three; and that they should dip into Wilson every morning, as the devout of the last century dipped into the Bible, because on every page there is some important reminder for the day.

The problem of problem-solving has been the hardest

problem for us to solve. These and other recent books represent a closer analysis of this problem than we have had before. In science, as in mountain-climbing, we have been going up at haphazard and by luck, too dazzled by the great ones to follow the short sure steps of their footwork; but the procedure can be codified and learned so that anybody can scale heights that even the great ones would not have dared a short time ago. Heretofore, problem-solving has been too vague for exact criticism to show what step went wrong, or what kind of speed can be expected. I think when this kind of close analysis actually gets into common laboratory and industrial practice, reinforced by an immediate response of exact criticism and mutual inspiration, it will amount to a further explosion of genius. For illustration I would like to quote here some of Polya's list of questions — questions to ask oneself when stuck on a problem — but I will not, for fear of making what is simple and profound and should be instinctive appear to be merely trivial. It may not seem very profound to tell the beginner in mountain-climbing over and over again, Use your leg muscles instead of your arm muscles, Use your toes and not your knees; but these are the first principles — ones that the outsider might think either unnecessary or obvious — that have to be hammered into him before he can be either safe or skillful. It is good to have books now to help do this hammering for intellectual climbers.

8. THE MOTIVATION OF CREATION

In the preceding chapter we spoke of the symbolic apparatus connected with thought and of various rules for making short sure steps toward intellectual accomplishment. Now let us look at the motives which keep this machinery running energetically and their exemplification in the work methods of particular men.

Every prospective scientist or artist has some long-range and perhaps dim ambition that motivates him, perhaps growing out of some childhood admiration or some disturbance, as they tell us. But no one becomes a great writer just by telling himself and all his friends at the table over and over about his ambition. The big motive has to be supported by the immediate desire to write, after each breakfast, and a line-by-line preference and satisfaction in doing this rather than anything else hour after hour and day after day. Anything a person tries to do without having this instantaneous satisfaction most of the time will be done badly or not at all. Our educational failure to create an equation-by-equation and test-tube-by-test-tube excitement and satisfaction in the work is, I think, responsible for the loss of many prospective scientists and for the routinizing of many others.

Recent experiments on learning in dogs show that if a problem is set up so that the dog comes perceptibly closer to his reward immediately — that is, within a fraction of