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Scientists and Engineers: Quantity plus Quality

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It is not my task in this paper to provide new statistical data on the current shortage of scientists and engineers in the United States. Rather, I wish to offer some opinions and points of view about the causes of the shortage and the possible cures for it. I shall try to state opinions that seem to be held by many scientists and engineers, and I take credit for no originality whatever. At the same time, I am not representing any organization or group, so I must assume full personal responsibility or blame for all opinions herein expressed.

U.S. versus U.S.S.R.

First I should like to make a few remarks about the production of scientists and engineers in the United States as compared with the Soviet Union.

It is perfectly obvious, of course, that one of the principal reasons for the immediate shortage of technical personnel in the United States is the grave military and economic contest we must wage with the U.S.S.R. We must attempt to be strong enough as a nation and to have strong enough allies to discourage any aggressive attack by the U.S.S.R. on the free world. Obviously it is necessary that we keep fully and intimately informed of the Soviet activities and achievements, so that we can prepare ourselves efficiently and effectively for the most probable cold or hot war contingencies. Our task is to maintain our security in the face of the threat of Soviet military and economic power.

These things we take for granted. At the same time, I feel that a good many Americans are getting a little sick of hearing the argument that *we* must do this or that just because the Soviets are doing it. What the Soviets are doing may be very important in deciding what we should do, but to conclude that we must always *copy* what they do may be fatally wrong.

Now we really know this. We do not send thousands of people to concentration camps just because the Soviets do. Nor do we deprive farmers of their land or deprive men and women of the comforts of daily living in order that all raw materials, labor, and productive capacity may be devoted to building a military machine. In these and other things that destroy the initiative or freedom or happiness of the people, the Soviets, one might say, are "ahead of us"—and we are glad of it!

But how often the newspaper headlines blaze with that dread phrase: "The Soviets are ahead of us" in something or other. What does it mean? "Being ahead" implies some kind of a race in which the two contestants are on the same track and going in the same direction. If instead they are on different tracks or are headed in opposite directions, who is to say which is "ahead"?

For example, the Soviets are said to have more submarines than we have; they are "ahead" of us. Does this mean we must hurry to build as many submarines as they have? *Not necessarily!* Their submarines are presumably directed at our absolutely vital sea traffic. Their sea traffic may be relatively small and unimportant to them. Hence, our submarines would have little to do, unless they have other functions. What we need is something to kill their submarines.

One can think of many other examples. Sometimes we should be doing the same things they are doing; sometimes we should be doing just the opposite, or at least something different. And I propose abandoning entirely the expression, "The Soviets are ahead of us." It usually has no meaning, and it often implies a false conclusion. Instead, let us just get the facts about what they are doing—and then decide for ourselves what is best for us to do.

We often hear that in the U.S.S.R. more men and women received degrees in science and engineering last year than in the United States. So what? Maybe this is because in the past 100 years they have so neglected their technical strength that they must now exert strenuous efforts to build it up. If this is true, then our rate of production should not be determined by their weakness—only by our own. Let us ask how many engineers *we* need to do *our* job and not take over their figures for the numbers they require to do their job.

Now we do need more engineers to do our job, so let us do what we can at our task without getting hysterical about *their* numbers.

After all, we might ask, what else can an ambitious young man or woman prepare for in the U.S.S.R. other than science or engineering? There is no great need there for stock brokers or bond salesmen! for lawyers or bankers or preachers! There are not many opportunities for opening up a new business. Even if one could get labor and materials, there would not be many people to buy autos or television sets or swimming pools.

But over there a career in science or engineering offers something to strive for: a fine salary, a car, a home in the country, respect of the public, and praise from the government—all the inducements that a rich capitalistic society could offer! Naturally, the young students flock into science and engineering careers.

Possibly in a few years the Soviets will have enough engineers, and they will decide they need more economists, say, or plant managers or agriculturists. If so, the government can quickly turn its

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smiles and approbation—and its rubles —to these new fields (possibly executing a few scientists for emphasis). And, presto, the younger generation will take the hint and go in the new direction. And a host of Americans will then hold up their hands in horror and say, "Look what the Russians are doing; we must do that too."

Now I do not want to be misunderstood. I am fully aware of the needs for scientists and engineers in the United States. But I urge that we view our need in the light of our own requirements—not someone else's. Only if we do this can we evolve a sensible long-range program that will serve the welfare and security of America.

We cannot build the kind of a society we want unless we offer our young people opportunities to go into any field they want or in which their talents lead them. And we shall certainly suffer if not enough smart youngsters go into business, law, economics, or government. Whatever we do to obtain more scientists must not be done at too great expense to other vital fields or to the freedom of choice of the individual.

The Shortage Is Long-Range

Let us turn now to the nature of our shortage of scientists and engineers. We hear the opinion expressed that, "since a large fraction of our technically trained people are now engaged on military and atomic-energy projects, therefore, as soon as the present cold war is over and the Department of Defense stops spending so much money, there will be thousands of engineers out of jobs—and they will be a glut on the market as they were in 1932."

This argument should be looked at squarely, for, of course, it contains some truth. A sudden abandonment or a large cutback in our military and atomic-energy program would result at once in large unemployment among eningeers—and among almost every other class of worker too, from truck driver to stock broker. How long this setback to our booming economy would last, no one could foretell.

However, we must not be blinded to the real situation that now exists by a paralyzing fear of improbable things that *might* happen. If we think our economy is going to suffer a staggering setback for any reason, we should stop training businessmen, doctors, lawyers, engineers—everybody! We should even stop having babies! Because, in case of economic catastrophe, we will all be hit in the teeth, as everyone was in 1932.

So let us not try to predict the future of the cold war, or the future economic conditions in this country or in the world. Let us simply ask whether at any given level of general employment in the coming years the engineer and scientist will be relatively more scarce or more plentiful than other types of workers. After all, everyone must risk the general rises and falls of the business cycle. But we should not push people into areas that are more likely to be overcrowded.

Now it is to me perfectly obvious that, if we ignore temporary ups and downs, the long-term trend has been and must continue to be for an ever larger fraction of our working force to be engaged in scientific and technical pursuits. This becomes strikingly evident if we look back, say, 50 or 100 years. In the United States while the population has doubled (since 1900) the number of scientists and engineers has increased 10 times. The fraction of the workers in technical pursuits has thus risen 5 times. Granted that this past 50 years has been a period of phenomenal growth in technology, I can see no reason to expect that the fraction of technical workers will not continue to rise—limited eventually only by the fraction of the population that possess technical talents.

I think this continued increasing relative demand is indicated by many factors: (i) The technologic age, in the world as a whole, has just begun to arrive. The United States will have tremendous opportunities to assist in the spread of the benefits of technology to its own people and also to other parts of the world. (ii) In this country, as we go forward, more research and development will be needed to produce more technologic equipment, which will need still more trained men to manufacture, maintain, and use it. This spiral will continue upward, limited only by our ultimate supply of brains. The frontiers of science have no foreseeable limit. (iii) As our industrial society progresses, we are using up at an ever-increasing rate the supply of easily obtainable raw materials with which nature provided us. We must dig ever deeper for our coal, iron, copper, oil, and other materials; we must process ever lower and lower grade ores at an ever-increasing cost in energy consumed and with an ever more intricate technology. We must find and make new materials, develop new sources of energy, take increasingly more elaborate precautions to attain adequate supplies of fresh water and pure air. Thus each and every person in the industrialized world will consume more energy, more natural resources, and the technologic needs must then rise always faster than the population. Even to keep pace with the rising population will be hard enough.

All these things will be true in the long run, whether or not the cold war continues or the military program is reduced. Even today a large fraction of those engaged in military work could very easily be fully absorbed in peacetime pursuits.

This picture can be changed, it would seem, only by the colossal disaster of an all-out nuclear war, which would set civilization back 100 years. Perhaps, as Harrison Brown points out, the world then without its once "cheap" sources of materials and energy could never return to its present state of existence.

The conclusion I wish to emphasize is simply that in the very nature of things we face the necessity, for a long time to come, to encourage and develop to the fullest all of our human brainpower in scientific and technical fields—and indeed in all other fields too. It is a long-range problem as well as a short-range one and justifies long- as well as short-range measures to solve it.

It would seem to me to be a relatively safe prediction that in 20 years—barring a world catastrophe—we will need twice as large a *fraction* of our working force engaged in science, engineering, and medicine as we have today. Maybe it will be 30 years. But the trend is in this direction, and the task will be a gigantic one. We had better explore the possibilities.

Sources of Supply

Short-range problems (that is, up to 4 years hence). Our most immediate, and indeed our only existing, source of supply of engineering talent consists of those already trained and at work in the field—our present reservoir. There are some 600,000 men and women in this reservoir, and one might say that there is nothing we can do to increase it. But there is. If we could improve the efficiency of utilization of these 600,000 people by only 5 percent this year, we would thereby add to the effective engineering force as much as all the new graduates of the class of 1956.

Can such a thing be done? I think it can. Let us consider some sources of inefficiency.

In the first place, since shrewd foresight is a great American virtue, it is natural for every industrial manager to save a few dollars for a rainy day, and also a few tons of steel, or copper, or aluminum, or oil, or whatever he might need. Why not at the same time stash away a few engineers too? They will come in handy if that next big contract comes through. And besides, they can be put on the payroll of the other Government contracts in the meantime and so it doesn't cost the company a dime to hang on to them!

How much of this goes on, if any? No one can prove a thing. But many an employed engineer will tell you that this is happening. Besides, it is not illegal and is, indeed, just ordinary business judgment—just a good example of that old-fashioned virtue of thrift. And this habit of thrift is probably a very difficult habit to eradicate. I do not even think of any "gimmick" that would eradicate it—in fact, most proposed remedies only make things worse and would penalize those who do not hoard. (Thrift, of course, is what *you* practice; hoarding is what the other fellow does!)

As with other problems, only a program of education and propaganda can help—possibly with contract penalties for unreasonable hoarding practices.

But there is gold in these hills of more effective utilization of engineers. Companies that have to pay for their own engineers learn to use them effectively. And I will wager that in any sizable company the engineers themselves could propose ways of reducing the staff, or at least of not increasing it. The Government contract officers could, no doubt, exert very strong influence for more efficient utilization, but this is a risky procedure.

Many engineers complain that companies often fail to recognize the difference between engineers and draftsmen. As a result, the desks of hundreds of engineers are jammed side by side in warehouse-type buildings amid all the clutter and clatter of typewriters, computing machines, and jangling telephones. It has been pointed out that to provide each engineer with his own small office would cost less than 1 year's salary, and it would improve his output, and that of his successors, for a score of years or more. We must never forget that the kind of engineering we are short of is not routine drafting but is hard, original intellectual effort—the kind of thinking that is elicited most fully only under the best of physical conditions.

Industry, however, is not the sole culprit. The Government too must take a great deal of blame for a low utilization factor for scientists and engineers. Inefficiency and incompetent leadership in its own laboratories, the conflict between military and civilian direction, red tape, lack of prompt decisions, are all frustrating barriers to effective work.

Furthermore, in its planning of the military-weapons program the Government is guilty of gross waste. Interservice rivalries and consequent duplication, the obsolete and cumbersome methods of making critical decisions and choices between rival enterprises or devices, the lack of any machinery for stopping any project that is under way—all these things require ten engineers to do the work of eight, or fewer.

I believe a very thorough and far-reaching change in the decision-making apparatus of the Defense Department in research, development, engineering, and production matters is called for if we are to eliminate a degree of waste that threatens to keep us perpetually short of technical talent.

I think I have said enough to illustrate the point: If we could utilize our present engineering talent more effectively, our shortage could be substantially reduced. But this will take strenuous, far-reaching, and intelligent efforts by government and industry.

However, this is the only way in which a short-range alleviation of our problem can be approached. It takes 4 years or more to educate an engineer. The number of engineers who will graduate 4 years from now—in 1960—is now fixed by the number who have already registered as freshmen for next fall. A certain percentage of these will fail or drop out; a few will swing from other fields into engineering and science. A good many freshmen who have not made up their minds can still be influenced. But, although I believe we should exert all efforts to improve our teaching and counseling and enhance our persuasiveness, these will have but relatively small effects for the coming 4 years.

Long-range problems (greater than 4 years). It is at the level of the high school—and possibly even more in the sixth to eighth grades—that the really important increases in future supply of trained technical talent is to be found. Of even the intellectually competent sixth-graders, 17 percent will not finish high school; 60 percent will not enter college; 70 percent will not finish college. Why?

Here we strike at the heart of our national problem. Why do not able young people go to college? Why do they not prepare themselves in larger numbers for science and engineering courses?

There are many, many reasons; and, in fact, for each individual child there is a unique set of factors that determine his decisions—factors made up of home environment; economic and social position; influences of parents, teachers, relatives, and friends; the atmosphere of the school; the skill of the counselors, if any; the quality of instruction; reading habits, and so forth. It is a striking fact that a very large percentage of the freshmen who do enter college trace their decision to a teacher or parent or friend who recognized their talent and encouraged its development. But think how many have gone unrecognized, undiscovered, and hence undeveloped—if not positively frustrated!

There has recently been organized in Oklahoma City a "Frontiers of Science Foundation" composed principally of business and professional men whose aim is to mobilize a state-wide—and eventually a nation-wide—effort aimed at the junior-high-school student, his parents and his teachers, to bring home the needs, the opportunities, the requirements, and the rewards of a scientific or engineering career. Traveling exhibits, movies, newspaper stories, public and private talks are being arranged. As a result of well-informed efforts, a real awakening is occurring in Oklahoma to the fact that science—pure and applied—furnishes the challenging frontiers of the future. I hope that the Oklahoma efforts will become national. Let us enumerate some of the things required for a nation-wide awakening of this sort.

1) Junior-high-school teachers in all subjects, especially mathematics and science, must be given more support and more rewards. They need higher salaries and better community recognition; they also need teaching aids (movies, laboratory equipment, and much more stimulating textbooks).

2) Counselors of young students need reeducation. Only too often students are advised away from science because it is said to be too technical, too vocational, or just too hard. "Return to the liberal arts," they say, "and make the world a better place to live. Scientists are just technicians and makers of terrible weapons." An astonishing amount of such nonsense is handed around. Science as one of the liberal arts—as a necessary part of every liberal education—has been overlooked. Mathematics—an essential language of communication in the modern world—has been allowed to degenerate into endless routine solutions of meaningless problems.

3) Parents of children—and this means men and women in all walks of life—must be brought in touch with the frontiers of science through newspapers, radio, television, magazines. They must get a glimpse of the values, the thrills, the rewards, the opportunities, in careers in science and engineering. They must see that their children are tested for their aptitudes and then encouraged and stimulated if they have mathematical or technical talents.

4) The scientist and engineer should be presented to the whole community in his true light—not as the absent-minded professor intent on blowing up the world; not as the cold-blooded technician who would be glad to see his machines crush men into extinction; not as the man who, if allowed to gain control, will lead civilization into soulless decay and physical destruction. Why not, instead, present the scientists and engineers as the men who have lifted civilization from dark-age feudalism and slavery to 20th-century liberty and enlightenment? It was knowledge of nature's laws that abolished the fear of demons; it was the steam engine that ended slavery; it was the power machine that gave men freedom from endless hunger-driven toil, and thus made all other freedoms possible and meaningful. The scientist and engineer, as human

beings and as benefactors of the race, must be brought to the people and to the schoolroom—in person!

5) These measures will help to motivate and encourage students of talent. But how do we discover the talent in the first place? We do not know! A competent and comprehensive program of research should at once be begun—or enlarged if already started—aimed at developing more satisfactory ways of discovering aptitudes in young people. Mathematical aptitudes are especially important. They are sufficiently specific to be detectable at an early age. When such aptitude-measuring techniques are developed, they should be used on a nation-wide scale to discover every youngster with potential technical abilities. We have spent hundreds of millions of dollars to search out and develop our resources of uranium. Are our nation's brains of less importance? Or was it brains that made uranium important?

6) We must find more cogent inducements to persuade boys and girls of talent to enter the study of mathematics and science, to prepare themselves for careers. Local and national college scholarship programs are excellent, but often do not reach down to the eighth or ninth grades. Contests, prizes, awards, science fairs, exhibits—maybe even comics and TV programs—could help. But the critical need is for more and better teachers.

7) Finally, we must recall that we have almost completely failed in the physical sciences and engineering to make use of the talents and services of women. Psychologists tell us that there is, statistically, no essential difference between the kind of mental aptitudes found in men and in women. Why are there not just as many female engineers as male, thus doubling our potential supply? Why indeed? There are some good reasons involving homemaking, motherhood, and the social custom that requires little girls to play with dolls instead of electric trains. But these reasons are not enough. Millions of women do work in spite of home duties and motherhood; indeed they work so that they can have better homes and more children. Junior science fairs have uncovered some very able girl scientists. Why not a nation-wide effort to attract girls into technical interests?

Tasks of Higher Education

I have said that the number of engineers we will produce each year until 1960 is already largely determined by the numbers now enrolled in our colleges and universities, and is not likely to be significantly changed. But this does not imply that our institutions of higher education do not have some important tasks to perform. The *quality* of the future scientist and engineer will be determined very largely by what the colleges do.

I must first emphasize, however, that we have been talking about *the* scientist or *the* engineer as though he were but one kind of person. Actually, scientists and engineers are of many types. Not only are they divided—horizontally, we might say—into the many subject-matter fields of specialization, but they are also divided vertically into a wide spectrum of different types or qualities. These different types range all the way from the trained laboratory assistant at one end to the most highly original and imaginative genius—the Albert Einstein, so to speak—at the other. The different segments of this spectrum are not always separated solely by differing degrees of intellectual capacity; they reflect also different qualities of interest, taste, and personality as well as combinations with other talents such as administrative ability, "sales" ability, speaking ability, or even physical strength.

There is a place for many types and combinations of talent and training. The competent assistant or technician is indispensable to modern research and development. So also is the competent "team research" man or the member of an engineering staff. So also is the sales engineer, the engineering supervisor, the laboratory director, the lone original research worker or designer, the skilled computer, the mathematical scientist, the patient systematic observer, the skilled synthesizer, the able teacher or lecturer or writer, and a host of others. We need men to penetrate the mysteries of nuclear forces and men to build dams and roads; men to learn the secrets of the stars and the structure of viruses; men to discover the nature of the chemical bond and men to make better steel; men to study cancer cells and men to dig oil wells; men to design skyscrapers and other men to air-condition them; men to keep the intricate machinery of transport and communication in operation; men to direct great enterprises of research, engineering, construction, and manufacturing.

Now obviously this is a big job for universities; maybe an impossible one. How are they going to turn out such a bewildering variety of specially trained people? They cannot, of course—and they should not even try. What they should do is to recognize that any particular student now enrolled might some day end up in any one of a dozen different kinds of jobs, even though he remains in the same subject-matter field. Hence, paradoxically, because a man will later specialize, the courses he takes in college should *not* be too specialized. Rather, they should provide a broad base from which the student can proceed in any one of many directions. A broad curriculum of studies in basic principles of science is called for, plus adequate experience in nontechnical fields such as the humanities and social sciences. There must be opportunities to explore new fields and to alter one's course in the light of newly discovered interests and talents.

All of these things the better schools of engineering and science try to do, but they could all do much better.

I think, too, that colleges and universities should face more frankly the range of intellectual caliber to be found among their students and the level to which each institution wishes to cater. At present no college dares to admit—even to itself—that it is going to cater to the middle or lower third of college students rather than the upper third. Each institution strives to get as many of the top 10 percent as it possibly can and then reluctantly goes down the list, admitting as many as it needs of the lower groups in order to fill the class. Naturally, some colleges have to hit the bottom of the barrel, particularly the state institutions that are required by law to admit all applicants with high-school diplomas.

As a result, most colleges will get a few top students, but the average level of ability will differ enormously from one institution to another. Of the top 25 percent of some college classes, only a small fraction would be even admitted to other colleges. Yet no institution has yet publicly advertised that it will accept only middle- or low-grade students, will design its curriculum for them, and will encourage all other students, both those below and those above certain limits, to go elsewhere. But why not? We do not entice a potential all-American fullback to come to Caltech on the assumption that he can get as good athletic experience and training there as he can at Notre Dame. Why does a college pretend it can serve all levels of intellectual ability? This is a good question!

Actually, the students themselves are not quite as dumb as we think. I understand that more than half of the 300 or so top men students of the country who won National Merit Scholarships chose to go to only a half-dozen institutions, all of which are generally recognized as being the most difficult in the country to enter. Those boys were smart enough to know that if they were smart enough to win a scholarship, they ought to go where the smartest students are to be found. Yet some people complain that this is being "unfair" to the smaller and less famous colleges. But I say it is unfair to the other 50 percent of those smart boys if they go to institutions where they will never have the competition required to develop their talents. If I did not mind risking my academic neck, I might even seriously suggest that the Merit Scholarship Board should not allow any of the winners in the top 1 percent of the country's youth to use their scholarship at any except a select few of the institutions of the country that have the proved capacity to give full challenge to top talent.

But if this is an impractical suggestion I can at least urge, first, that every able student find out for himself which institutions can offer him the greatest challenge, and, second, that every college give especial attention and encouragement to those exceptionally gifted young people who do attend.

And this leads directly to the heart of the most important of all problems facing us in this country: the improvement in quality of education. Improvement of quality is necessary in all fields—business, law, politics, government service. But especially in scientific and engineering work is quality of education of prime importance. In the field of manual labor, if one man cannot lift a stone, possibly two or three men can, or a machine can be found to do it. But in the scientific or engineering field it is not assured that if one man cannot solve a problem then two or three or more can solve it. And certainly no machine will of itself do it. The law of addition or multiplication of forces does not hold in the intellectual field. A single Einstein may accomplish a solution which a thousand lesser men could never attain. In the Manhattan District Project during World War II, 1000 scientists and engineers were needed to complete the task in time. But the towering talents of a relatively few men like Fermi, Bethe, Wigner, Oppenheimer, and a dozen others were decisive in setting the pace of the effort. Fermi needed many men to help him in his pioneering experiments. But the other men alone, even though their number had been doubled or trebled, might not have obtained the answers. Creative ideas, in other words, occur in the minds of single individuals. Hence, the pace of progress is determined by the quality of individuals rather than their numbers, and when quality is sacrificed for numbers we may get weaker rather than stronger.

I do not wish to imply that quality can always be improved by reducing numbers. Plenty of very large universities have produced scores or hundreds of men of distinction, and plenty of small colleges have never turned out one. The goals of quality and quantity are separable; under proper conditions both or either may be obtained. But we do not attain either one if our whole attention is given to the other.

In short, while we expand our efforts to see that every competent boy and girl in America—every single one—has the full opportunity to develop his talents, we must not at the same time give up the goal of improving the quality of our educational system all along the line. We can address ourselves to both tasks. They are not necessarily mutually exclusive. Nevertheless, there are certain practical limitations to the rapid achievement of the double goal. The practical limitations are—as in most problems—of two kinds: money and people.

It is possible to double the classroom space of a school and also to improve the quality of instruction. But it costs more and takes more good teachers. Therefore, we are frequently tempted to build the classrooms and neglect the teachers.

We dare not neglect either the qualitative or the quantitative problem. Yet we are often unable to solve them both at once. I can offer no simple formula that will resolve the dilemma. I can only emphasize that both quality and quantity are important and that while many others are crying for more engineers I would like to enter a plea also for better ones.

What does it take to get better ones? It takes, first all, the things that I have been talking about: better public schools, better teachers, better counseling, better testing and selection, better opportunities for study of mathematics and science, improved attention to the gifted student. At the college and university level, it means similar things—improvement in quality all along the line.

In particular, however, I think it is important that a few institutes or schools of science and engineering be encouraged to devote their resources to the sole task of improving quality without trying to grow in size. If, for example, a dozen top institutions could obtain enough additional annual income to bring their faculty salaries to a level where the flow of top young people away from teaching could be stopped, the country would be repaid many times over.

I do not pretend that this would be a popular suggestion, or even a possible one. Certainly I should not want the task of choosing the institutions. Only a private foundation could face up to that task. And, although the $10 million a year that might be required is small for the country as a whole, it is an enormous sum for any single foundation. In terms of endowment, for example, it would involve another gift the size of the recent Ford Foundation gift to colleges ($250 million), but this time divided among a dozen or 15, instead of more than 600, institutions.

Advanced Training

The need for improved quality of engineers is a need for engineers who are more creative—that is, for men with the ability and training to pursue new ventures, to develop new ideas or techniques or equipment, to participate in research and development programs. In the field of science it is now taken for granted that either a master's or a doctor's degree is a prerequisite for a career in the field. It is widely assumed, however, that 4 years' training is adequate for an engineer. There is, indeed, a large field for the 4-year graduate; but if the top 25 percent, say, of the engineering graduates could be encouraged to go on to an advanced degree, with possibly 10 percent of them pursuing the doctoral degree, the quality of the nation's research and development effort could be substantially improved. The quality would be improved, first, because the graduate schools would admit only those selected men who by temperament, ability, and previous training are competent to pursue creative activities, and would then give these men experience with the frontiers of engineering and with the techniques of creative work. It is, for example, especially important that we have more engineers of exceptional ability in theoretical work. In aerodynamics, hydrodynamics, mechanics, structures, materials, and other fields, there are tremendous opportunities for the man with sound and extensive mathematical training and with experience in theoretical research. We are realizing more and more that advanced engineering development consists of not only the invention of gadgets but also the solution of highly complex mathematical and theoretical problems. Only extended graduate training can produce the men required.

Therefore, I propose that the nation give more extensive attention to the selection of engineers for graduate work, to the building up of graduate work and research in schools and institutes of engineering and technology, and to the more adequate support for creative engineering research in these graduate schools of engineering. There are many serious problems that impede such an effort.

First, there is the financial problem facing the individual student. When a young bachelor's-degree graduate in engineering can go immediately into a job that pays him between $400 and $500 a month, he must be confronted with powerful counter arguments to persuade him to decline such offers and to continue his educational career. There are several things that can be done to provide such inducements. Industries themselves can stress the importance of advanced training for those who are competent to profit by it. Both industry and government can provide additional fellowship funds to assist in reducing the economic barriers to advanced graduate work. There are also possibilities in developing programs of part-time employment in industry for those who are carrying on graduate work.

I should like to emphasize, however, the dangers of this latter course. Graduate work, to be valuable in developing creative engineers, is not the type of training that can be provided by attending three classes a week—possibly in the evening hours—and working at a regular job the rest of the time. Research work is not a series of college courses; it is a way of life. And I do not believe that either a scientist or an engineer can become fully qualified for research and development work unless he has actually lived full time in the atmosphere of a graduate institution, fully immersed in some phase of its research program. It is quite possible, of course, for a man to have an industrial job during the summer months and it is also quite feasible, if commuting distances are not too great, to work at a job 10 or 15 hours a week and still carry on a normal full-time graduate program. Nevertheless, it should be recognized that every hour spent away from the campus, from the classroom, the library, or the research laboratory is something to be avoided if possible, for it detracts from the full-time devotion to the life of research—a life that must include time for reflection and study.

Therefore, I should like to urge universities to use their influence to stem the spread of so-called "cooperative programs" in which it is assumed that graduate work and training for research can be achieved in only a few hours a week spent in a university classroom, while the student is carrying on a nearly full-time job. At the same time, I would urge industry to develop methods of expanding their fellowship programs and other ways of making it possible for their employees to spend full time on their graduate work and still receive adequate stipends.

Another barrier to the expansion and improvement in quality of graduate work in engineering is, of course, the matter of teaching. First-class creative engineers, who are the only ones who can supervise first-class graduate study, are in great demand in industry at salaries that are, quite normally, at least double the salaries available in even the best paid university faculties. Here, therefore, I must repeat the suggestion I made a short time ago that a few schools of engineering in the country which already have good graduate schools be given adequate support to increase the salaries of their key people by 40 to 75 percent in order to keep and attract the top-notch engineers required for an adequate graduate program.

These then are a few of the things that should be done to improve both the quality and quantity of our engineering and scientific manpower. Much of my argument can be summed up by saying that we ought to take our capitalistic system more seriously; we ought to offer larger rewards to those doing the most important jobs. Fifty thousand dollars does not make a good engineer; but it may prevent a good one from being diverted to other pursuits.

Factors Limiting Higher Vertebrate Populations

Paul L. Errington

At times, in seeking to generalize, a student of animal populations may feel that almost anything can and does happen or that the one common propensity of animals is to live if they can and die if they must. Nevertheless, some patterns are coming to stand out in the population dynamics of many species of animals.

My own studies of such patterns have dealt with what are commonly thought of as limiting factors in mammal and bird populations, and, in this connection, I have observed that important aspects of competition and predation may be particularly misleading if certain natural relationships and adjustments are not adequately taken into consideration. The following discussions will therefore present some of my ideas of distinctions that are worth keeping in mind when one attempts to analyze effects of competition and predation on population in at least mammals and birds (*1*).

Competition and Habitat Selection

There may be circumstantial evidence seeming to link changes in distribution or abundance of animals with changed intensity of competition. Of two closely related or closely associated species, one gains as the other fades. But, is one species displacing the other or "competing it out," as through greater aggressiveness, or are both merely responding to such habitat changes as are favorable or unfavorable to one or the other?

We do know that ascendancies and declines of bobwhite quail and of certain species of grouse have accompanied different stages of human settlement in the north-central United States, and we know that, for the grouse—pinnated, sharp-tailed, ruffed, and spruce grouse—the habitats of one species grade off into habitats of the next species ecologically in line. Yet the segregation of these native gallinaceous birds into their own niches is not so complete that it rules out possibilities of tension zones where one species could well have a depressive influence on populations of another. In cases marked neither by overt antagonisms nor by destructive impacts of one species upon the other's food supply or general environment, evidences may be seen of differential mortality or of withdrawals of one species into poorer habitats. But, again, in so many cases of what *could* be significant interspecific competition, we must return to such questions as: How much may the observed phenomena be due to something else—for example, to responsiveness to habitat niches?

The distinguishing features of habitat niches for a species are often too elusive for human perception. The main criterion for judgment may be the behavior of the species, itself, considered over sufficiently long periods of time to be meaningful. Svärdson (*2*), writing of competition and habitat selection in Swedish birds, describes the establishment of wood-warbler breeding territories at the same places but by different individual male warblers each spring. Despite local differences in topography, vegetation, and light conditions, selection of the old territorial sites by newly arrived, strange birds proceeds according to pattern each year. After very intensive studies, McCabe and Blanchard (*3*) concluded that the three species of California deer mice with which they worked have

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