Identifying and Encouraging Potential Scientists

The most challenging aspect of education today.

by John R. Weir

The demand for high-level talent continues to increase – particularly for scientists and engineers. Efforts to meet this demand have been directed mostly toward improving our educational facilities. However, if we are going to develop our human resources to the fullest, the early identification and encouragement of potential scientists is of equal importance.

The high school science teacher is in the key position to identify and encourage the future scientists of America. Through increased knowledge of the psychological characteristics of the high-level scientist or engineer he can make an earlier identification of those students with the potential for success in these fields. Once this is done he can provide the experience and training necessary to develop these potentials.

It is evident that this fact will assume ever increasing importance in the decades ahead. When we consider some of the important elements in an industrializing world, it is clear that the demand for technological knowledge will continue to grow.

I. POPULATION

Populations are increasing the world over, and will continue to increase. It has been estimated that, after a million years of man's existence, in the year 1000 A.D. there were about 300 million people. Only by 1830 – almost 1,000 years later – did world population reach one billion. By 1930 – 100 years later – the second billion was added. By 1965 – 35 years later – the third billion will be added. The UN has estimated that it will take 15 years to add the fourth billion, and 10 years to add the fifth. By the turn of the century there should be six billion people on the earth.

Not only is world population increasing rapidly; the rate of increase is increasing as well. Between 1850 and 1900, world population grew about 0.7 percent per year, doubling the population every century. Between 1900 and 1950 the average annual rate of increase was 0.9 percent, shortening the doubling time to 75 years. The projections for the period from 1940 to 1980 predict a rate of increase of 1.3 percent, a doubling time of only 50 years. This means 6 or 7 billion people by the end of this century, and perhaps 12 to 14 billions by 2050.

II. FOOD

With all these people about to appear, the matter of food immediately becomes of importance. It seems probable that a large proportion of the human race has never had enough to eat. We find references to starvation and famine throughout recorded history, and they continue to appear even today. The reason for this is fairly simple. In the period from 1900 to the beginning of World War II, total world food production increased 10 to 15 percent, but in the same period of time world population increased 30 percent. The war decreased food supplies over most of the earth's surface and the pre-war level was not regained until 1952. But by that time there were many more millions of people to feed. So, there are more people than ever in the world today, and they seem to be getting hungrier.

James Bonner, professor of biology at Caltech, has studied world food problems and has concluded that if we made a maximum effort to apply all of the technology that we have at the present time to all of the potentially cultivable land on the earth's surface,

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we could produce just enough food to feed these future populations by the time they arrive. Obviously, it would require a tremendous number of scientists and engineers to make such an effort.

III. RAW MATERIALS

Before the Industrial Revolution few consumer goods were manufactured, and only small quantities of raw materials were needed to produce them. With the advent of the Industrial Revolution the machine operator could turn out many more products – but he consumed more raw materials in the process.

An industrialized nation consumes raw materials in vast quantities. For example, the per capita annual steel production in India is about 9 pounds per person. In the United States it is 1300 pounds. India consumes 1/10th of a barrel of oil per person per year, the United States 170 times as much. Obviously, it takes a great amount of technological skill to design and build the equipment necessary to consume raw materials at this rate.

When U.S. levels of consumption are examined in conjunction with the demands of underdeveloped countries, it seems clear that the world has a tremendous challenge ahead of it. If the present peoples of the world now living at extremely low levels of consumption (approximately two billion persons) were brought up to the standard of living of the contemporary United States, we would have to extract from the earth each year 18 billion tons of iron, 300 million tons of copper, 300 million tons of lead, 200 million tons of zinc, 30 million tons of tin, and huge quantities of other metals and non-metals. These are totals that are well over 100 times the present world annual rates.

Surely, a tremendous technical effort will be necessary to reach these higher rates of production.

There is also the matter of the richness of ore deposits. For all of man's existence, up to the last century or two, raw materials have assumed a relatively unimportant part in his struggle for survival. He fashioned only a few artifacts from raw materials lying on the surface of the earth. For example, he could pick up pure copper, fashion it into tools, and use it without further treatment. However, with increased industrialization, uses of copper increased many-fold, and the copper ore that was available decreased in purity. Some time ago we were processing 5 percent copper. Today this has dropped to 0.8 percent. We can certainly look forward to its dropping to an even lower level, perhaps to 1/10 or even 1/100 of 1 percent.

Where will this end? How low can one go in obtaining necessary raw materials? According to Harrison Brown, professor of geochemistry at Caltech, the lower limit is found in ordinary igneous rocks. These contain most of the elements that are necessary for the perpetuation of a highly industrialized society, and in proportions that are not unreasonable from the standpoint of their industrial use.

One hundred tons of average igneous rocks contains, for example, 8 tons of aluminum, 5 tons of iron, 180 pounds of manganese, 40 pounds of nickel, 20 pounds of copper and 40 pounds of lead. Many of the elements which are not found in sufficient quantity in igneous rocks – such as chlorine, bromine, and iodine – can be found in the oceans. Other elements like nitrogen and oxygen are readily available in the atmosphere. Still others can be found in the practically inexhaustible supplies of limestone, which is a source of carbon; in gypsum, which is a source of sulfur; and in phosphate rock, which is a source of phosphorus.

Given the necessary energy, and enough technological knowledge to develop the processes of extraction, the people of the earth *could*, if need be, support themselves entirely with the leanest of ores, the waters of the ocean, the rocks of the earth's crust, and the air around them.

Here again, vastly increased technical development will be necessary.

IV. ENERGY

It takes energy to extract metals from low-grade ores. It takes energy to manufacture equipment. It takes energy to run it. It takes energy to produce food. Current world energy consumption is about 3.7 billion tons of coal per year. If all the people in the rest of the world were to expend energy at the current per capita rate of the United States, consumption would increase sixfold, to the equivalent of approximately 22 billion tons of coal each year. This is a rate of consumption that would exhaust the fossil fuel reserves of the world in 40 or 50 years. But it is also a rate that is dictated by the U.S. standard of living, which is envied by the rest of the peoples of the world.

To meet the increased demand for raw materials, food, higher standards of living, and industrialization, we must develop other sources of energy.

Dr. Brown has calculated that in every ton of ordinary granite, energy which is equivalent to about 15 tons of coal can be economically extracted in the form of localized uranium and thorium. This means that from the long-range point of view man will be able, if it becomes necessary, to extract his energy needs from the very rocks of the earth's crust – the same rocks that can supply the variety of metals needed for the support of a highly industrialized civilization. However, again, this immediately implies the development and application of very advanced technological skill.

Population is going up exponentially. World energy consumption is increasing exponentially. The richness of raw materials is decreasing. These trends warn us of the tremendous demands for technological and scientific knowledge we will face in the future. In fact we are already facing them in the shortages of engineers and scientists we have witnessed in the last several years – shortages that may possibly be even more clearly understood in the light of past trends.

In the United States in 1900 there were 11 million farmers, in 1950 only 7½ million. Yet in 1900 the 11 million represented 38 percent of the working force, while in 1950 they represented only 13 percent of a labor force that had doubled to 60 million. So, while the labor force had increased rapidly, the proportion of farmers in this labor force had dropped.

Even greater changes occurred among the professions. In 1900 one million professional and technical workers made up 4½ percent of the labor force; by 1950 this group had increased fourfold and now constituted 7½ percent of the working force.

A current report of the Department of Labor notes that, for the first time in the history of the United States, the number of persons employed as professional, office, and sales workers exceeds the number employed in manual occupations. The Department predicts a growth rate for professional and technical workers that is nearly double that for any other occupational group. It expects no change among unskilled workers, and a continuing decline of farmers.

These early trends in the change in demand for high-level talent are now becoming more meaningful. If they continue in the same way for the next 50 years, we will need two or three times as many scientists as will be available.

This is a unique situation. We have no past experience upon which to draw in considering the problem. Furthermore, the shortage of high-level scientific talent is going to be long-lasting – partly because of the forces of world industrialization, and partly because of the complex pattern of personal qualities and experiences necessary to make a scientist or engineer.

At the present time this shortage of high-level talent is perhaps only inconvenient. In the future it will become critical. Therefore, any success in combating it will be of great importance to the future of our society. There are many avenues of approach to the problem, but one of the most important involves the early identification of potential scientists and engineers.

Such early identification and encouragement would go far toward reducing our present waste of high-level talent. And we certainly are wasteful. In the United States only one-third of those young people capable of doing college work actually go on to college. Only one-half of the *very* capable, and only two-thirds of the *exceptionally talented* go on to obtain college degrees. Thus we lose two-thirds of the capable, one-half of the very capable, and one-third of the exceptionally talented – or approximately half a million college graduates each year.

Of all groups that contribute to the development of scientists and engineers in the United States perhaps high school teachers are the most influential. They provide the capable student with his first major exposure to science as a body of knowledge, and to the scientific method as a technique for gaining more knowledge. They are the ones who may provide the inspiration or exhibit the enthusiasm and satisfaction that can be gained from working in science.

To become a scientist a student must make educational and vocational decisions in the 9th, 10th, and 11th grades – long before he has the information or the experience necessary to choose a lifetime career. The high school science teacher is in the most strategic position to help him select goals that are appropriate and attainable.

The science teacher is also in the most strategic position to identify the potential scientist or engineer, and to encourage him to consider science as a career. The more skilled the teacher is in making this early identification, the better he can provide the information and experience that will help develop the student's inclinations toward science.

Little is known at present about the psychological characteristics of potential scientists. However, current research in the psychology of occupations does provide some basis for their identification early in the high school years.

There seems to be a general pattern of psychological abilities and traits that is typical of people in technological occupations. Within this general pattern there are more specific sub-patterns, typical of different kinds of technical activities (such as theoretical scientist, experimental scientist, engineer, sales engineer, technician). The pattern for the high-level research scientist is one of the better known ones. In broad outline, it is as follows:

I. INTELLECTUAL ABILITY

It is necessary to have a certain amount of intellectual ability in order to do the kind of thinking and learning that a scientist must do. But this is more than just having a high IQ. In reality it means having a specific pattern of abilities.

In his analysis of the thinking processes, Professor J. P. Guilford has, to date, identified almost 50 different elements or factors that make up "mental activity." It is probable that different scientific activities require different patterns of factors for success, but these patterns have not yet been worked out. For current early identification we must content ourselves with what are probably groups of factors. For example, to have the best chance of success in a science curriculum a student should be high in quantitative ability, abstract reasoning, symbolic reasoning, understanding logical relationships, and recent and remote memory.

II. VALUES

Many high school students take the Allport-Vernon Study of Values – a psychological test for measuring an individual's value system. It measures aesthetic,

continued on page 26

economic, religious, theoretical, social and political values. Of these, the potential scientist scores high on Theoretical and low on Economic and Social values.

III. OCCUPATIONAL PREFERENCES

Many high schools routinely administer the Kuder Preference Record to their students for vocational guidance purposes. It measures the kinds of activities the student prefers. The potential scientist has a clear pattern on this test. He should be highest on the Scientific and Computational scales, and somewhat less high on the Literary and Musical scales. He should be lowest on the Persuasive and Social Service scales, and somewhat low on the Clerical and Mechanical scales.

IV. OCCUPATIONAL INTERESTS

The Strong Vocational Interest Inventory measures the degree to which the student's likes and dislikes compare with those of people who are successful in a variety of occupations. The potential scientist scores high on the scales for Artist, Psychologist, Architect, Physician; and on the group that includes the Physicist, Chemist, Mathematician, and Engineer scales. He is also high on the Math-Physical Science Teacher, Musician, and Certified Public Accountant scales. These are the occupational groups whose patterns of likes and dislikes are similar to his. He scores low on the Banker, Mortician, Real Estate Salesman, and Life Insurance Salesman scales. These are the groups whose likes and dislikes are the opposite of his.

V. PERSONALITY TYPE

Lastly, the potential scientist has a specific approach to the world around him. He prefers his intuitions to his senses. He responds more to inner hunches or intuitive possibilities than to the actualities around him. The impressions that come to him from the outside via his senses are much less important to him than the ideas and implications he can derive from them. He prefers thinking to feeling.

In his formation of judgments and values he is systematic, objective, and impersonal rather than sympathetic or antagonistic, personal or subjective. If logic dictates, he will act counter to his feelings. He is introverted rather than extroverted. His main points of reference are internal and are focussed on his ideas, thoughts about himself, and private personal concerns. He gives secondary consideration to the external world of people and things. In David Reisman's term he is inner-directed.

He also tends to withhold judgment until all the facts are in, and he has had a chance to order and rationalize them in terms of his own private system of standards and values. As a consequence of this style of life he tends to be quiet and reserved and somewhat uncomfortable in casual social situations. He is primarily interested in his studies and does very well in them. He is usually original and brilliant in scientific and theoretical subjects. Skeptical, critical, and independent, he is always open to new facts, new experiences, or new conditions without prejudging them. He is generally very determined and often stubborn; he can sometimes be led, but never driven.

With the addition of personality type to the patterns of interests, preferences, values, and intellectual factors, we have what might be called the research scientist profile.

Obviously, a specific scientist will not always match this profile in detail. With as complicated and elaborate a set of patterns as these, there are many ways in which the individual might deviate. But the more closely he matches the profile, the more likely it is that he will have the abilities, motivations, and inclinations to find science a satisfactory and rewarding career. The more he deviates and the more he approximates the profile of some other occupational group, the less likely it is that he will continue to pursue a scientific career.

When we look at what comprises the profile – intellectual abilities, values, preferences, interests, and personality type – it is immediately evident that these are not human characteristics that can be developed overnight in college or high school. In a sense, they begin to develop at birth, with the interaction between an individual's genetic makeup and his environmental experiences. They take a lifetime to form, continuing to crystallize throughout much of adulthood. However, having begun at birth, the profile has much stability by high school age, and by then cannot be drastically altered. Neither the high school nor the college can make a "scientist" out of a "non-scientist." But these patterns often become visible in rather primitive form even before high school age. It *is* possible, then, to make earlier identification than we commonly do today, if we will only pay more attention to what we already know, and if we will work diligently to learn more about these patterns.

This early identification is of crucial importance, because we can provide the most inspiring experiences for a student only after we have identified his unique potential.

Here, then, is the challenge to our industrial society. Only through maximum use of our high-potential talent can we maintain the rate of growth that we have experienced in the past. Only by an increased knowledge and use of these patterns for early identification can high school teachers help their students realize their potential more fully – and can the teacher become more effective as a teacher. This is indeed the most challenging aspect of education today.