Technology and Social Change

Special education of engineers and scientists for participation in emerging countries is essential.

H. E. Hoelscher

For nearly three decades, the United States and other world powers have been engaged in programs to help the less developed nations to improve their social, economic, and environmental conditions. Some of these programs have been quite significant in their effects. Others have been barely marginally successful. Many have failed. We have often devoted funds to projects which were technologically too far ahead of the environment they were intended to serve and in which they were planned to function. We have offered help to do things which were not always wanted, much less needed, by the receiving country, and the force of our bank account has sometimes made it difficult for others to tell us "no." We have "guided" developmental efforts without a full appreciation for the complexity of the total problem structure, without considering the effect that a specific project, even if successful, might have on a total economy, or even whether it could operate successfully at steady state within that economy.

For example, we install sophisticated air-conditioning equipment in an African hospital only to discover that frequent failure is a characteristic of the local power supply and many millions of dollars worth of air conditioning becomes a nearly inoperable monument to our technical genius and our planning inadequacies. Equally important, the waste is obvious to those whose needs remain unsatisfied.

We establish medical programs which successfully reduce infant mortality rates and increase the life-span of a people. But our failure to consider mechanisms whereby the food supply in the region may simultaneously be increased makes hunger the inescapable consequence.

We build a modern fertilizer plant but, in the absence of shipping facilities, roads, and railroad lines, the product from that plant may serve only a limited area. In the United States we think quite naturally in terms of large tonnage productions to lower unit costs as far as possible; tonnages which cannot be shipped are worse than useless.

The United States' political, economic, educational, and industrial systems have evolved under conditions specific to our country, most importantly, with the existence of an informed and responsive citizenry. However, there are fewer than 11 radio receivers per thousand of population in India while there are more than 1200 per thousand in the United States. Almost every small town in the United States has a newspaper of its own and the New York *Times* delivered daily. India has fewer than 600 newspapers and relatively few people who live in the more than half million villages ever see one. Conditions are not the same.

Educational systems throughout our country are uniquely suited to the total operation of the United States, but there is no reason to believe that they will work equally well in other countries.

Our management methods cannot be applied to most developing countries, and less developed cultures will often strongly resist our business management techniques. A recent article in *Forbes* magazine makes this point. One of *Forbes*' reporters traveled to Latin America to interview 30 Peace Corps Americans with M.B.A. degrees, men trained to manage American industry. The point of the article was: Forget your past, forget your fancy education, you're in a new ball game. Specifically, forget much of what you learned about finance, because there is no way to raise money publicly in Colombia or Peru. Forget systems analysis, there are no computers. Forget the "decision tree," you'll do much better relying on persuasion. Forget that you're a respected M.B.A.; the Latin American businessman has never even heard of the degree. But you'd better learn humility and patience. Those M.B.A.'s accustomed to getting things done quickly have graduated from the "rat-race" to the "turtle-race." Those who adjusted helped through commonsense analysis of the problems facing the local economy, rather than through high-powered management techniques.

It must be noted that those in the less developed countries are not entirely blameless for many of the only partially successful assistance programs requested and accepted from the Western world nor are they faultless in the failures which have been sustained. Local special interests, an often stubborn adherence to tradition, obfuscation of issues for regional advantage at the expense of national progress—all these have deterred real and significant change in some cases. In addition, those in the developing nations have often had as little appreciation for the total problem structure as those who have tried to help.

If these comments seem totally negative, this is not intended. There has been much progress and we have helped. The difference between conditions 20 years ago in the countries of Southeast Asia, Africa, and Latin America is real, significant, and speaks eloquently of the efforts of many dedicated people in the governments, foundations, and educational institutions of many countries. Improvements in village water supplies through the use of tube wells, malaria control, mills driven by electricity and mechanical rather than human power, vast improvements in housing, in clothing for cold weather, in educational opportunities, and in the awareness of the people of their right to participate in the politics of their country are examples of positive change for good. There are many more. But, there is very much yet to be done.

Some Problem Details

For example, the food index in the developed regions of the world, an index of total food available per capita, is paralleling or rising slightly above the population growth rate curve.

However, in the developing regions—the countries of Southeast Asia, Africa,

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and Latin America—although total food availability is rising dramatically, per capita availability is actually decreasing. The gap between the nourishment available per person in the developed and the developing countries of the world is widening despite the massive efforts devoted to agriculture and food production in the past 20 years. James Bonner of the California Institute of Technology has said that the food projections for the developing regions, in either the relative index or in calories available per capita per day, show a probable downward trend during the next 30 years (*1*)—clearly a situation which can only lead to *world chaos*.

Among the best indices of technological development are energy production and consumption. In the United States, electrical energy production during 1965 was about 5000 kilowatt-hours per capita. In this same year, energy production in Chile was about 680 kilowatt-hours per capita, approximately 13 percent of that in the United States. Ecuador, one of the more underdeveloped nations in South America, produced less than 100 kilowatt-hours of energy per capita, approximately 1.9 percent of that in the United States. India, a much larger nation than Ecuador, and surely much more highly industrialized, produced even less energy—approximately 50 kilowatt-hours per capita, less than 1 percent of that of the United States.

Energy consumption in the developed countries today is equivalent to approximately 12 tons of coal per person and seems likely to grow on a reasonable extrapolation to nearly 100 tons of coal per person by the end of this century. In India, energy consumption per person is approximately 1 percent of that in the United States and the prospects for growth seem dim. Once again, a marked disparity appears to be widening despite our best efforts to close the gap (*1*).

Finally, the world's waste products amount to about 5 pounds per person per day and people generate heat under reasonably active conditions at a rate of about 1000 watts. Our civilization also generates noise in large, but thus far, nonmeasurable, quantities. No basis for quantifying this pollutant is yet available. Waste, heat, and noise must be considered important contaminants and the source of important future problems. In 1954, the United Nations estimated that the 1980 population of the world would be approximately four billion. Today, it is clear that that estimate was in error by at least one-half billion human beings. Those extra half billion people will produce 2.5×10^9 pounds of waste per day or, at a density of 1—that of water—a square mile covered to a depth of 2 feet every day. The heat they will generate will be sufficient to boil an amount of water equal to a lake 10 miles long by 10 miles wide and 10 feet deep every hour of the day.

In terms of world economics, the picture is equally troublesome. The largest increases in per capita income have been occurring regularly in the highest income countries of the world. The 1965 per capita gross national product in the United States was $3800 and is anticipated to be $15,000 within four decades—approximately a fourfold increase. In India, through the same four decades, even the most optimistic analysis predicts less than a twofold improvement (*1*, p. 12). The outstanding indebtedness of the less developed countries has almost doubled since 1961. Debt service payments have grown somewhat faster than earnings from exports in such countries. The prices of exports from developed countries have gradually risen in comparison to the prices of exports from the less developed countries, and trade among developed nations has increased more rapidly than their trade with those who are less developed. Grant and grant-like assistance to the less developed nations has actually decreased during the past half decade (*2*).

The task is made more difficult by the lack of reliable information in sufficient quantity. In the new monumental work by Gunnar Myrdal (*3*) the significant portion of chapter 11 is devoted to the unreliability of statistical information about the national output and the structure of these economies. The problems of information-gathering within these countries, the questions of a proper basis for comparison with conditions elsewhere, the uncertainty of exchange rates and of the real value of money in these countries, and the differences in the meaning and significance of figures reported, supposedly on the same basis, from country to country, make our task more difficult.

Such problems are obviously enormous in both complexity and in dimension. They are also enormous in their importance to the present and the future economic and political stability of the world—as well as in their prime importance to human welfare. Those which are purely physical problems, problems of science, engineering, and technology, as well as those which are economic in character can and will be solved. Of this we can be reasonably certain. However, these physical problems carry with them sociological, political, and cultural problems which are even more staggering, more difficult to identify, more nearly impossible to quantify, and, perhaps, more drastic in their effect on our civilization. There is not now a basis for an equal faith that their solution can or will be found. How then, can we evaluate, assess, or anticipate the problems arising from the interactions of the nonscience and almost-science areas with those professions which are blessed with analytic tools and methods based more or less soundly in fact and theory? How can the interface between the two, mismatched, married today by necessity, be smoothed to permit effective cooperation? There is no single easy answer. But this is clear. In a world in which demand seems to increase more rapidly than resources become available, we must move forward on a different basis.

Need for a Technological Base

A technological base is clearly the most effective starting point for change in the economic, social, and political conditions of a nation. It thus seems wise to do those things which will help a country to industrialize. But we must recognize that the basic purpose of this assistance should be to help construct a foundation upon which the people of the country can then generate their own industrial superstructure, from their own national point of view, to serve their own unique needs. A skyscraper cannot be built from the top down. We clearly cannot export our own technology intact; our industrial superstructure may not fit upon their industrial base, and it may not fully mesh with the social, political, educational, and economic structures whose form is peculiar to the heritage of that country. An industrial complex is an individual thing where countries are concerned. It must be something like a personal wardrobe, tailored to fit a way of life, an economic situation, a relative affluence, a need, and a capability of maintaining and operating what then should be an asset. We cannot and should not attempt to impose our technology wardrobe on another nation. Theirs must be appropriate to their needs and their conditions.

For a technology in any nation to be economically viable, it must mesh effectively at all interfaces with the social, political, economic, and legal structures of that nation. A technology which is critically dependent upon highly sophisticated electronics or controls in a nation where appropriate skills are lacking cannot be effective. India, with its abundant supplies of labor must relate this supply to a technology which is labor oriented. Similarly, the specific character of the raw material resources, the health patterns, the transportation facilities, and the legal and financial structures of the nation all influence the development of its technological base. Engineering is not international in the same way that science is. The nuclear or theoretical physicists at work in India discourse with colleagues throughout the world in a universal language. The results of their activities are evaluated on their merit without concern for the national or cultural source of those results. Unlike science and its language, mathematics, which are truly international, engineering is effective only as a local dialect. The engineer must take into account the conditions prevailing in a specific country or region in which his efforts are to function.

How to proceed? There are several different attitudes about industrialization in these nations. First, there are those who claim that technology must always develop in response to stimuli and needs arising within the society itself. Developments in the United States were evolutionary, relating at each stage to the level of sophistication and organization reached by our society. It is thus suggested that efforts to short-circuit these processes overseas, to play technological leapfrog by introducing technologies which are more advanced than the society can support or tolerate, disrupt the society, aggravate unemployment, and accomplish little of long-range value. It is suggested that force-fed technological development (i) yields little benefit to the agricultural sector of the economy; (ii) gravitates to the more densely populated parts of the country and yields benefit only to a narrow circle if at all—occasionally, such developments cause job destruction in a wider area; (iii) often fails because the highly trained personnel required for such capital-intensive industries cannot be provided from the local labor market as rapidly as needed—there is a limit to the speed at which such people can be trained; and (iv) depends heavily on extensive imports of machinery and, often, raw materials—this can upset the balance of payments or place the country under heavy obligations for grants-in-aid (*4*).

There are many good examples. The introduction of Western automatic machinery into the Indian glass industry during the last decade has been nearly a total failure. These were intended to replace the traditional hand-operated machines. The resultant new industry is heavily dependent upon foreign exchange, has not created significant employment, and has tended to impede, if not cripple, local initiative. Compare this experience with developments in the leather industry. Under inspired leadership, the Leather Institute in Madras accepted the limitations imposed by conditions unique to India: basically, the fact that hides available as raw material for the industry are distinctly inferior to those considered necessary for the industry in the West (they would, in fact, be considered unacceptable). Using native raw materials, they have developed new techniques to suit their own conditions. The resulting leather industry not only produces goods competitive on world markets but is distinctly viable as a part of the Indian scene. It produces goods, values for the economy of the nation, and employment. Furthermore, this was done using men and women from all castes in spite of some extremely strong traditional caste taboos against work or even contact with either hides or leather.

The problem of unemployment in the developing countries is reaching alarming proportions and capital-intensive technologies introduced into this situation aggravate that unemployment. Intermediate technology is suggested, a technology *appropriate* to the need and to the technological, social, economic, and political state of the country or region. Such industries can be developed and located where the people are actually living. Production methods can be simple so that the demand for high skills is minimized, and production should be based on local materials and local markets. This will then have a multiplier effect throughout an ever-widening region. This is an effort which will enable the masses to help themselves and to participate in the process of development. Men thrown out of work by new technology in the industrialized West are often rapidly absorbed by another new technology, which itself has resulted from the first development. This absorption rarely occurs in the developing nations.

Examples of successful "intermediate" technology are readily available from the files and publications of the Intermediate Technology Group of the United Kingdom formed in 1965. One of their publications lists under appropriate headings 31 categories of inexpensive equipment and tools. The following examples are reported elsewhere (*5*).

Bakery industry. Steam pipe ovens which ensure an even dispersion of heat by means of coiled steam pipes; drawplate ovens in which the loading and unloading are speeded up by putting the plate of the oven on wheels and rollers; T-arm kneaders in which a single reciprocating arm kneads the dough in a rotating mixing bowl. This equipment is more advanced and efficient than brick-lined, open-frame ovens and hand mixing, but is much less capital-intensive than turbo-radiant traveling ovens or continuous mixers.

Ceramic industry. Hand-operated jiggers for forming plates, semi-automatic presses for tiles, gravity-fed extruders for pipes. These are all superior to traditional methods but less expensive than tunnel kilns and fully automatic equipment.

Shoe industry. Simple sewing machines (first introduced in 1859) for stitching the sole of the upper and insole. This is quicker than hand stitching but may be more appropriate than vulcanizing or injection moulding equipment for soling in some countries.

It is thus suggested that the best long-range answer to the social and economic development of the nations of Asia, Southeast Asia, Africa, and Latin America is via development of viable technologies which largely depend on the sources and strengths within their own borders and which produce the goods and services required by their own people.

There is another point of view. Those within the developing nations maintain that they *must* leapfrog over intermediate stages. They hold that the slower process would forever prevent their catching up. There is much relevance to this argument, and whether this or the slower development will in time produce the desired lasting results is not known. However, it is clear that both attitudes are extant.

Need for New Talents

Whatever the route, we can assist. We must, for reasons of obligation to a substantial segment of the humanity of our world and equally for our own selfish, long-range interests in world political and economic stability and in world markets. However, our efforts can only be valuable if we aid them in *their* efforts toward *their own* goals—not ours—by starting at the bottom of their technological pyramid.

Whatever the best procedure, the active participation of engineers as central figures in the required team effort, perhaps even in leadership positions, will be necessary. This will demand a new kind of engineer or, at the very least, new attitudes for those in the profession who wish to be involved. It will require engineers who can recognize and integrate the complex array of social, political, economic, health, and legal factors. It will require a *systems approach*, an organized, mathematical, structured, objective approach to the total systems problem which is the emerging country. This engineer must be able to provide the links between knowledge, the consequences of its use, and the inherent dynamics of the developing society. He will need to be capable of perceptive analyses and understandings of historical, sociological, cultural, and anthropological factors.

These factors will vary from country to country. The answers for each will undoubtedly be different. About the only common factor to be expected, a priori, is that the efforts will be slow to yield measurable results, that progress toward the goals will be slow. The industrial strength of the United States began with what we now call "small" industry, with a single entrepreneur, possessed of or by an idea, an ambition, and a need. From such beginnings have grown du Pont, the Ford Motor Company, and the other industrial giants of our nation. We have no reason to assume that the successful process will be different elsewhere.

It also seems obvious that the universities of the world must continue to accept the challenge of preparing young men and women for participation in the effort to solve the problems of the developing countries. However, such preparation must, in the future, be different from anything available today. It must be broad in its coverage of the traditional academics, penetrating to the problem structure for which it is designed. It must produce graduates able to integrate knowledge from many fields, thus synthesizing something new, something not now available. Such programs must provide more than rearrangements of old clichés for new times. They must be different in ways not now obvious.

"Humanities" in engineering curricula was the subject of a quite extensive study (*6*). The need, the problems involved in present efforts to satisfy that need, and the national attitudes among engineering and liberal arts educators toward this part of the curriculum are discussed at length. The report does not, however, strike to the central problem.

Over the years and in response to many pressures, engineering educators have increased the amount of course work in the social sciences, economics, political sciences, and humanities throughout their curricula. This has largely been done in a kind of patchwork manner, by dipping here and there into the offerings of the appropriate liberal arts departments for electives. These courses are usually chosen as much for their availability or for their attractive reputation as for their content or relevance. Thus, courses in the liberal arts appear too often in an engineering program like raisins in a plum pudding; social sciences or literature courses seem dropped untouched into the engineering mix. The assumption apparently has been that the occasional liberal arts course will flavor the whole mix and, simply by being there, will permeate and influence the total specialized engineering focus thereafter. Little effort has been made to adapt courses in the humanities to the needs and interests of the engineering student. Indeed, content and relevance are usually given very low priority. We cannot prepare engineers for international development by this technique. Something more is needed.

That "something more" must be courses which are designed for the needs of the engineering student, courses which are not designed to lay the foundation for a specialist in economics or political science or sociology but which are, rather, designed to provide foundations for the generalist. Such courses must pull together threads from several disciplines within the so-called liberal arts and provide the basis for an understanding of the social and political structures and dynamics of many different parts of the world as it is today. Engineering students cannot, in general, find such courses within the standard catalog of offerings from the separate liberal arts departments. Engineering faculties must, therefore, seek the cooperation and involvement of those within the liberal arts in an effort to meet a new and vital need. We must seek ways to provide new courses in these areas—political and social science plus economics—courses which are much more relevant to the needs of engineering students. Such courses can be academically of highest quality, intellectual challenge, and of unquestioned pedagogic content, broader in scope while no less challenging in content. They must not be narrow. Some efforts have been made in this direction (*7*). A bare start has been made by many who are concerned but more must be done.

Two further comments may be offered. First, all this does not constitute an argument for the 5-year bachelor's degree program in engineering. These are not clear nor compellingly sufficient arguments for adding to the length of time required for this first professional degree. Many seem to believe that only by adding course work to our present programs can the content of the curricula be made more relevant to the needs of modern engineering.

Second, much of this could be directed equally to those who major in the so-called "liberal arts." It seems incredible that universities today produce thousands of graduates from liberal arts programs to take positions in a world dominated by technology in all its successes, failures, and problem structures, and yet these students are not exposed to any real understanding of the base from which all this arises. Some lack exposure even to the terminology of that scientific-technological base. This entire paper might also have been directed toward the nonliberal "liberal arts" curricula in our universities. Perhaps, this is partly what our students in those programs are so concerned about.

Conclusion

If we are then convinced that a strong and viable technology growing within the structures native to a country is needed to provide a base for lasting social and economic and environmental changes, and if we are convinced that developed nations, including the United States, must continue to provide assistance to this development, then we must begin to educate young men and women for the task. Engineering certainly provides one possible—perhaps the most attractive—starting point. But such young people must operate with a sense of the appropriate, the sensible, the economical, and with an appreciation for the impact of their efforts on man, his society, and the total system. They must be equipped to anticipate the interactions of technology on society and vice versa. Perhaps, all this is evident, obvious, trite, a collection of truisms. If so, the obvious should be accepted and appropriate new programs planned.

References and Notes

1. "The Next Ninety Years," *Proc. Conf. Calif. Inst. Technol.* (California Institute of Technology, Pasadena, 1967), p. 5.
2. I am indebted to N. K. Rao of the Ford Foundation for calling my attention to these factors.
3. G. Myrdal, *The Asian Drama* (Pantheon Books, New York, 1968), vol. 1.
4. This listing is suggested by J. Porter and A. Latham-Koenig, *Develop. Dig.* **7**, No. 1, 43 (1969).
5. *Human Resources for Industrial Development, N.S. 71* (United Nations International Labor Organization, Geneva, 1967), p. 201.
6. S. P. Olmstead, *J. Eng. Educ.* **59**, 303 (1968).
7. One of many examples is the new course "Humanities and Philosophy," developed for and now being offered in the engineering curriculum at the University of Pittsburgh. As an example of what has been done in a developing nation, one might examine the courses being offered at the Indian Institute of Technology, Kanpur. Other specific examples can be provided by the author.

Photosynthesis and Fish Production in the Sea

The production of organic matter and its conversion to higher forms of life vary throughout the world ocean.

John H. Ryther

Numerous attempts have been made to estimate the production in the sea of fish and other organisms of existing or potential food value to man (*1–4*). These exercises, for the most part, are based on estimates of primary (photosynthetic) organic production rates in the ocean (*5*) and various assumed trophic-dynamic relationships between the photosynthetic producers and the organisms of interest to man. Included in the latter are the number of steps or links in the food chains and the efficiency of conversion of organic matter from each trophic level or link in the food chain to the next. Different estimates result from different choices in the number of trophic levels and in the efficiencies, as illustrated in Table 1 (*2*).

Implicit in the above approach is the concept of the ocean as a single ecosystem in which the same food chains involving the same number of links and efficiencies apply throughout. However, the rate of primary production is known to be highly variable, differing by at least two full orders of magnitude from the richest to the most impoverished regions. This in itself would be expected to result in a highly irregular pattern of food production. In addition, the ecological conditions which determine the trophic dynamics of marine food chains also vary widely and in direct relationship to the absolute level of primary organic production. As is shown below, the two sets of variables—primary production and the associated food chain dynamics—may act additively to produce differences in fish production which are far more pronounced and dramatic than the observed variability of the individual causative factors.

Primary Productivity

Our knowledge of the primary organic productivity of the ocean began with the development of the C^{14}-tracer technique for *in situ* measurement of photosynthesis by marine plankton algae (*6*) and the application of the method on the 1950–52 *Galathea* expedition around the world (*5*). Despite obvious deficiencies in the coverage of the ocean by *Galathea* (the expedition made 194 observations, or an average of about one every 2 million square kilometers, most of which were made in the tropics or semitropics), our concept of the total productivity of the world ocean has changed little in the intervening years.

While there have been no more expeditions comparable to the *Galathea*, there have been numerous local or regional studies of productivity in many parts of the world. Most of these have been brought together by a group of Soviet scientists to provide up-to-date world coverage consisting of over 7000 productivity observations (*7*). The result has been modification of the estimate of primary production in the world ocean from 1.2 to 1.5×10^{10} tons of carbon fixed per year (*5*) to a new figure, 1.5 to 1.8×10^{10} tons.

Attempts have also been made by Steemann Nielsen and Jensen (*5*), Ryther (*8*), and Koblentz-Mishke *et al.* (*7*) to assign specific levels or ranges of productivity to different parts of the ocean. Although the approach was somewhat different in each case, in general the agreement between the three was good and, with appropriate condensation and combination, permit the following conclusions.

1) Annual primary production in the open sea varies, for the most part, between 25 and 75 grams of carbon fixed per square meter and averages about 50 grams of carbon per square meter per year. This is true for roughly 90 percent of the ocean, an area of 326×10^6 square kilometers.

2) Higher levels of primary production occur in shallow coastal waters, defined here as the area within the 100-fathom (180-meter) depth contour. The mean value for this region may be considered to be 100 grams of carbon fixed per square meter per year, and the area, according to Menard and Smith (*9*), is 7.5 percent of the total world ocean. In addition, certain offshore waters are influenced by divergences, fronts, and other hydrographic features which bring nutrient-rich subsurface water into the euphotic zone. The equatorial divergences are examples of such regions. The productivity of these offshore areas is comparable to that of the coastal zone. Their total area is difficult to assess, but is considered here to be 2.5 percent of the total ocean. Thus, the coastal zone and the offshore regions of comparably high productivity together represent 10 percent of the total area of the

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