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The Modern Scientific Enterprise

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On April 16-17, 1947, explosions and fires on the wharves at Texas City, Texas, were responsible for 576 deaths and $67 million damage. Ammonium nitrate, a chemical fertilizer which was being loaded onto two ships in the harbor, was the cause of the disaster. The incident was a sensation. Once again the average person had reason to think of a chemical as something dangerous. Probably the image the chemical industry had then was not much different from the image it now has. Is it not true that chemicals explode, pollute our air and water, and cause many diseases, such as cancer?

The popular idea of what the chemical industry is like has been easily extended to the rest of the scientific enterprise. (For the purpose of this article, "scientific" pertains to the physical, environmental, engineering, mathematical, life, and agricultural sciences; the social sciences are not included.) Life scientists tinker with life as they engineer genetic changes. Civil engineers are heartless people who destroy urban neighborhoods with new superhighways. Agricultural scientists encourage practices which lead to short term gains but long term losses as arable land is destroyed. Physicists dream of better ways to kill people with bigger bombs.

The first purpose of this article is to examine the scientific enterprise from a more objective point of view. This perspective will show that the modern scientific enterprise is neither all good nor all bad, but it is, nevertheless, something with which society must cope. The second purpose of this article is to discuss the reaction of the Christian community to the modern scientific enterprise. It will be shown that the Christian community supports a prevailingly negative attitude toward this enterprise, and some suggestions for change will be made.

A Large Effort

First of all, the scientific effort is very large. Consider three facts:

(1) Each year in the United States approximately one million people receive their last academic degree, bachelor's or higher. About one-sixth of those degrees are in the sciences.[1]

(2) The number of people engaged in scientific work in the United States is about twenty-five per ten thousand population.[2] At least one-third of the population is in the labor force, and therefore about 0.75% of all U.S. workers are engaged in scientific work.

(3) The United States spends annually about $50 billion, slightly over two percent of its gross national product, on the scientific enterprise, that is, on basic research, applied research, and development.[3]This does not include the amount spent on science education.

A comprehensive picture of the scientific enterprise would include information for all the branches of science on a world-wide scale. Because it is not practical to make such a presentation here, the following limitations will apply in this discussion: First, much of the information given will be for the science of chemistry. Second, most of the discussion will be for work carried out in the United States. It is possible, however, to make approximate extrapolations from chemistry to all of science and from the United States to the entire world. For example, about one-tenth of the U.S. science degrees awarded are in chemistry or chemical engineering.[4] It would seem, therefore, that about one-tenth of all scientific work is chemical work. An extrapolation to the amount of world scientific activity can be made by considering that 35-40% of all scientific publications originate in the United States.[5]

The data cited so far give a general picture of what goes into the scientific enterprise with respect to education, work, and money. What are the benefits of this enterpise?

Consider first the number of research projects whose results become known. One indication is given by one of the principal activities of the American Chemical Society. The main reason that this society holds national meetings is to hear presentations of its members' research. Currently there are well over two thousand such presentations at each of the Society's semiannual meetings. Naturally, U.S. chemists also give many research talks at other meetings.

Research reports are not finalized, however, until they appear as articles in technical journals. Over 100,000 scientific articles (not just chemical articles) originate in U.S. laboratories each year. Thus, at least four U.S. scientific articles appear each year per ten thousand population. In addition, there are about 2.5 patents issued to U.S. citizens per ten thousand population.[6]

Another way to appreciate how much research is published is by noting how many abstracts appear annually in *Chemical Abstracts*, which publishes abstracts of chemical and chemically-related articles appearing anywhere in the world. (Since chemically-related articles are included, the scientific work covered is more than all of chemistry but less than that in all of science.) *Chemical Abstracts* publishes abstracts of articles taken from over twelve thousand journals;[7] over 400,000 such abstracts were published in 1978.

The total numbers of articles and patents which appear give us only a measure of how much research is published. An unknown amount of successful research is kept secret. For example, a company might keep its research secret in order to have an advantage over its competitors; or research results might not be disclosed for military reasons. Also, a considerable amount of unsuccessful research goes unpublished. The total amount of research carried out, both published and unpublished, both successful and unsuccessful, is therefore much more than reflected (for the United States) by the four scientific articles and 2.5 patents per year per ten thousand population. The conclusion that the modern scientific enterprise is very large is inescapable.

Because of the scope of the scientific enterprise, there is rapid growth in the amount of scientific work done. Such growth is illustrated by the following facts concerning twentieth century trends:

(1) In 1900 there were about 9000 chemists and chemical engineers in the United States; in 1950, about 77,000; in 1970, about 125,000.[8]

(2) The total U.S. expenditure on basic research, applied research, and development, that is, on the entire scientific enterprise, increased (in constant dollars) more than three-fold between 1953 and 1976.[9]

(3) Between 1907, the year *Chemical Abstracts* began, and 1948, this journal published 1.5 million abstracts. Since 1948 well over five million abstracts have appeared. This rapid increase in the number of abstracts means that a chemist who completed his formal education in the early 1960's can claim that one-half of the body of chemical knowledge has been developed since he left school. For most chemists who graduated at that time, the fraction would be well over one-half for their own areas of interest, since chemists and other scientists tend to work in the newer, fast-developing subdivisions of their disciplines. One count of abstracts illustrates this point: the annual number of abstracts in the "subatomic and radiochemistry" category of *Chemical Abstracts* increased by a factor of about twenty between 1948 and 1978. (This category was represented by one *Chemical Abstracts* section in 1948; by 1978 this section was subdivided into five sections.)

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(4) In the 1970's the annual number of science graduates obtaining their last degree, bachelor's degree or higher, has been more than twice the corresponding number for the late 1940's.[1]

The Result

Trends in the chemical industry are a measure of scientific achievement. It has become commonplace to claim that every product of the chemical industry is made possible only because that industry invests heavily in research. Furthermore, most chemical companies state that all of their current production is possible because of the research of recent years. As a result, the research carried out by chemical companies produces huge sales in chemicals. In 1979 there will be over $60 billion in sales of industrial chemicals and synthetics in the United States. If allied products are included, the figure is $130 billion.[10] That amounts to per capita sales of $270 and $590, respectively.

These chemicals are not sold directly to the ultimate consumer, the buyer of retail products. Yet the consumer can easily see that much of what he spends is for products made possible by chemical research. For example, during 1975 the third largest health care expenditure in the United States was for drugs and sundries. Approximate per capita costs were as follows: hospital care, $210; physicians' services, $100; drugs and sundries, $50. The last amount was about 9% of the total health care cost.[11]

Of interest is a typical specific achievement, the production of gasoline, discussed by R.L. Pigford in his survey of a century of chemical technology.[12]

To obtain gasoline, so essential for our economy, it is not enough to have a large supply of petroleum or the means of separating petroleum into its component parts. Also necessary is a certain kind of chemical reaction, a "cracking" reaction. Before 1936 the only way one could obtain gasoline was to heat petroleum. Heating produced gasoline in two ways: first, heat separated from the petroleum any gasoline initially present; second, heat caused some cracking. But the total amount of gasoline which could be obtained was small and it was of low quality. In 1936, however, catalytic cracking was invented. By 1950 chemists and chemical engineers had developed the complicated and difficult "fluidized catalytic cracking" process. Part of the difficulty lay in the problem of processing tremendous amounts of petroleum, up to ten tons per minute in the largest units. The process is truly awesome: tons of solid catalyst continually move from the region of the cracking unit in which gasoline is made to the part of the unit in which the solid catalyst contacts hot air. The function of the hot air is to burn off the catalyst the residue which accumulates when the catalyst contacts the petroleum. Then within minutes the catalyst returns to the region containing petroleum. If the hot air should somehow mix with the petroleum, the resulting conflagration would be beyond description. In spite of such difficulties, the worldwide capacity of these cracking units is about fifty million barrels per day.

The scientific enterprise is not merely the sum of all such achievements. Just because this enterprise is very large, it has had certain effects on the people involved in it. First, the scientific enterprise is too large to be as centralized as is sometimes supposed and therefore a significant number of scientists have experiences characteristic of small companies, small schools, small research establishments, and small governmental units. What this means with respect to geographical distribution in the United States is the following: the highest concentration of chemists is in the middle Atlantic states and the lowest concentration is in the mountain states, just as one might expect. But the number of chemists per ten thousand population in the middle Atlantic states is less than twice the corresponding number in the mountain states.[13] Thus, no large area of the country has even twice the concentration of any other large area. Decentralization is also indicated by the number of different establishments which employ chemists. Besides being employed by a large number of schools and government laboratories, chemists in the United States are employed by over 650 major employers and numerous minor employers.[14]

The scope and growth of the scientific effort help determine the attitudes society has toward scientists. Two attitudes are evident, and one of these is negative. At the beginning of this article some of the negative ideas the public has concerning scientists were given. Scientists build bombs, cause pollution, and so forth. Without doubt, some of this criticism is justified.

Christians, along with all mankind, live intimately associated with scientific activities and scientific results. In order to live normatively in this world and in such a way as to whow that it is the Lord's world, the Christian community must first realize that the very large and expanding scientific enterprise is here to stay.

But on the other hand, if one considers how society uses and pays for the services of scientists and their findings, he finds a positive attitude. One measure of attitude is how well the individual scientist is paid. Consider once again the experience of chemists. Their salaries indicate that society regards them as highly as other professionals. In 1978 the median starting annual salary for all chemists with a bachelor's degree was $12,700; the median for all bachelor's degree chemists with experience was $22,000. For Ph.D.'s the corresponding figures were $21,000 and $27,400. Chemical engineers' salaries were significantly larger; for example, the median salary for a person having experience and a bachelor's degree in chemical engineering was $30,000.[15]

What Do These Things Mean for the Christian Community?

Christians, along with all mankind, live intimately associated with scientific activities and scientific results. In order to live normatively in this world and in such a way as to show that it is the Lord's world, the Christian community must first realize that the very large and expanding scientific enterprise is here to stay. The present negative attitude toward science and some suggested changes concerning what the attitude should be are discussed by looking at Christian colleges — and, where it applies, Christian secondary and elementary schools. Three questions arise.

(1) How is science treated in Christian colleges and other Christian schools? In these schools fine things about science are said and it is claimed that the whole earth is the Lord's. Yet it is possible that the attitude of the Christian community toward Christian colleges parallels attitudes of more than a century ago. At that time many people in higher educational institutions had a very low opinion of the sciences, especially "useful" science.

It finally became necessary, in order to prepare students for the so-called practical jobs, to start land-grant colleges. These colleges emphasized subjects in the general areas of agriculture and mechanics. There was a philosophical split between two concepts of education, concepts reflected in the two kinds of higher educational institutions. By comparison, the Christian community today has a tendency to leave the practical tasks to public colleges and universities, just as years ago the practical task was left to the land-grant colleges.

It was pointed out earlier that about one-sixth of U.S. college graduates are in the sciences. Obviously, one-sixth is no magic fraction or a goal to be sought after. Yet it is probably true that the corresponding fraction in Christian colleges is much smaller. Why?

To a certain extent the Christian community nourishes the idea that public schools can take care of the practical task. Thus, it is widely held that certain disciplines, such as those related to human behavior and to religion and philosophy, can be taught very well in Christian colleges. But other disciplines, chiefly the sciences, are thought to be neutral and therefore taught adequately in a common-denominator establishment, such as a public college or university. Young man, do you want to become a youth cousellor? Then, by all means, study at Christian College X! No? You wish to become an engineer? Why, they have the best possible program at State A & M.

Christian colleges and lower schools ultimately determine the attitude of the Christian community on these matters. One can easily over-state the case. Yet in these schools it seems that there is considerable nostalgia for the days when scholars communicated in Latin and the only science allowed was that which was very basic and very, very abstruse. Schools exhibit this attitude in several ways. Consider, for example, what courses secondary schools offer. Too often it is the public secondary school student, not the private secondary school student, who has the opportunity to take extra science courses in preparation for a scientific career.

To ascertain the attitude at the college level, try to name a Christian college which in its very first year puts as much emphasis on science as on any other area. Which Christian colleges plan to have science play as large a role as it plays in state-supported college and university systems? It might not be impossible to find such schools. But surely the fact that such schools are not easy to find indicates something about the attitude of the Christian educational community toward the scientific enterprise.

(2) Would it cost too much money for the Christian community to provide significantly more for the scientific enterprise? The quick objection to what we have just claimed about Christian education is that the Christian community simply cannot afford to support scientific activity in the schools to the extent that it is supported in public secondary schools, colleges, and universities.

One could make such a case by looking only at costs for medical schools, research institutes attached to universities, and similar kinds of specialized education. By citing such examples the argument is won on economic grounds, not on principle. The question should rather be one of agenda. Does the present agenda call for the eventual formation of a medical school? A scientific graduate school which owns a cyclotron and a very large computer? If the agenda of the Christian community does not call for such professional and graduate schools, it is not surprising that the community has also been slow in developing an adequate number of engineering schools, nurses' training schools, and many other undergraduate scientific programs.

It is not for a lack of money that these goals are not achieved. If the hearts of those in the Christian community were set on achieving these goals, a small effort could be begun and eventually an institution which the Christian community desires could be obtained. There is sufficient precedent for that kind of planning in the Christian community. Surely there is not a multimillion dollar church building or mission program anywhere that does not hark back to the day when it all started with a scant half-dozen worshipers meeting in a basement and pledging themselves to go ahead in faith as the Lord would lead them.

Furthermore, the Christian higher educational community could carry out some scientific work without large outlays of money. For example, what mathematical breakthroughs have been made in the Christian community? How many Christian colleges have graduate programs in mathematics, where expensive equipment is not required but where it is necessary to believe that mathematics is an area in which the Lord is to be glorified?

It is not a lack of money which has prevented the Christian academic community from demonstrating that scientific activity must honor the Lord. The Chrisitan academic community will be off the track as long as it clings even slightly to the idea that God's providence is a little more important in some disciplines — such as those related to religion, philosophy, and man's behavior — than in the scientific disciplines.

(3) What kind of educational attitude must the schools have to meet the scientific challenge? Encouraging more students to go into the sciences is not enough. Christian educational institutions, and smaller public institutions as well, have made three errors here.

The first error is not to have adequately developed some of the skills needed by the science student and eventually the scientist. For example, there is not an insistence at all levels to be proficient in working with numbers. The de-emphasis of education in numerical calculations corresponds to a diminished interest in precise thinking and abstract ideas. No doubt the change is only a slow one, not as dramatic as claimed by some who examine trends in standard test scores. But there surely has been a change for the worse and it seems that only a monumental effort will reverse the general trend. Raising the achievement level of the student population should mean that there will also be an improvement in the group of students who choose scientific studies.

More dramatic than the drop in the skill level of the student population has been the significant loss of self-discipline among students. Even without idealizing the past, we certainly can conclude that there was a time when schools disciplined students so strictly that finally, after many years, discipline became self-discipline for many students. After all, it was once assumed that all secondary school students were to study in the school's study hall. It was also assumed that when a college built a dormitory that it had thereby also built a place where students would study. Scientific studies suffer considerably when there is a feeling among the student population that one can do one's "own thing."

The third error is the prevailing attitude toward "relevance." Surely one is impious if he seems to say a word against relevance. Relevance is indeed good — with one very important proviso. That is, it should not be necessary to *prove* to the student that what he studies is relevant. It should be enough to be able to tell the student in some cases, "In the long run, perhaps after many years, you will find useful whatever you have learned of this subject. Then you will see that this subject is relevant." If students will not accept such a claim, then they are not trained properly. Teachers of sciences are probably most guilty in this matter. It is easy for science teachers to seize upon the environmental pollution and energy problems, put them into basic courses, and pronounce these courses relevant. The result is that students believe that what they learn in each class period must, somehow, have immediately visible relevance to their lives. Consequently, teachers encounter increasingly greater difficulty in teaching the truly big things, the things which take a long time to teach and which might not be useful to the student until he has matured in his chosen field of study.

Another example is apropos, this in a non-scientific discipline. The English-speaking educational establishment probably made a very big mistake when it decided that Latin, a "dead" language, was no longer relevant. It is true that Latin students never were thrilled to learn of the many relations between Latin and English. Yet large numbers of older persons who many years ago studied Latin, perhaps for only a year, now testify that Latin continually helps them use English. For them Latin has indeed become relevant.

Summary

The scientific enterprise is large, influential, and will have at least as great an effect on human lives in the future as it does now. But the Christian community has not come to grips with what is happening; after all the discussion carried out in the Christian community, it still acts as if some part of creation is neutral. The prevalent attitude, expressed particularly in modern Christian education, does not stimulate significant scientific activity within the Christian community. Christians have often criticized the scientific enterprise and have correctly identified distortions when there has been too much growth in one area at the expense of growth in another area. They have seen through the vain claim that only scientific activity can provide true meaning. But these criticisms and insights will not amount to much if the Christian community does not intend that its own scientific effort is to have an impact.

Notes

[1] Panagis Benetatos, *Professionals in Chemistry: 1974* (Washington, D.C.: American Chemical Society, 1975), pp. 83-84.

[2] National Science Board, *Science Indicators 1976*, (Washington, D.C.:GPO, 1977), p. 7.

[3] "Real Growth in R&D Forecast by Battelle," *Chemical and Engineering News*, Jan. 1, 1979, p. 8.

[4] Benetatos, p. 7.

[5] National Science Board, p. 11.

[6] Ibid., p. 15.

[7] Bryce Crawford, "The Nature of the Transition," in *Proceedings of the Symposium on Chemical Abstracts in Transition* (Columbus, Ohio: Chemical Abstracts Service, 1974), pp. 2-11.

[8] Benetatos, p. 3.

[9] National Science Board, *Science at the Bicentennial* (Washington, D.C.: GPO, 1976), p. 16.

[10] David Kiefer, "Slower growth in 1979 could put earnings in jeopardy," *Chemical and Engineering News*, Dec. 18, 1978, pp. 24-26.

[11] "Chemistry in Medicine," *Chemical and Engineering News*, Dec. 5, 1977, pp. 28-33.

[12] Robert Pigford, "Chemical technology: the past 100 years," *Chemical and Engineering News*, April 6, 1976, pp. 190-203.

[13] Benetatos, p. 61.

[14] "1979 Career Planning," *Chemical and Engineering News*, Oct. 23, 1978, pp. 39-48.

[15] "Salaries of experienced chemists increase at all degree levels," *Chemical and Engineering News*, Oct. 23, 1978, pp. 29-30.