The changing relationship between science and technology

J. Langrish of the Manchester Business School examines the way in which the relationship between science and technology has changed in the past and is about to change again.

In recent years, the belief that technological change is somehow based on scientific advance has been increasingly challenged. Price[1], for example, has claimed: "The naive picture of technology as applied science simply will not fit the facts. Inventions do not hang like fruits on a scientific tree. In those parts of the history of technology where one feels some confidence, it is quite apparent that most technological advances derive immediately from those that precede them".

Technological change has been increasingly seen as the adaption of existing technological concepts in response to demand. Schmookler[2], for example, has attempted to show that the variation in inventive activity between different American industries is explicable in terms of the variation in demand, concluding that economic growth determines the rate of inventive activity rather than the reverse. None the less, governments have continued to invest in scientific research at a level much greater than other activities which can also claim cultural and prestige benefits. Science receives much more money than the Arts because it is believed to be useful. When science is not used, it is claimed that there is a communication barrier; the alternative possibility that it is intrinsically of no use is not examined.

One of the major problems in looking at the usefulness of science is a matter of definitions. What is Science? What is Technology? To avoid this problem, we must ask questions such as, what is the effect of university research and research in government laboratories on industrial change, or on improvements in health and agriculture.

A study[3] of 84 British technological innovations showed that "demand pull" occurred more frequently than "discovery push" and that out of 158 key technical ideas made use of in innovations, 56 originated within the innovating firms and of the remaining 102, 7 came from a British university and 17 from a British government laboratory (including Research Associations).

The apparent conclusion that ideas from British universities had little effect on British innovation was challenged in a variety of ways. One of these was the claim that although industrial innovation may be based on industrial research, the day to day progress of industrial research depended on university research in ways that would not be revealed in looking at 'key ideas'. It was pointed out, for example, that industrial chemists spend time reading the results of university chemical research.

To examine the relative contribution of university research in the literature cited by industrial researchers, seven review articles written by British industrial chemists were examined[4]. The reviews contained 567 references to other publications (including patents) and the institutional origins of 396 of them were identified. Only 23 out of the 396 references were to the work of British universities and of these, 7 stated that some industrial finance had been involved in the research. British government institutions seemed to be more interesting to the industrial reviewers in that 45 of the references were involved. Table 1 compares the relative importance of the institutional origins of the 102 "key ideas" with the origins of the 396 references and also the origins of 452 abstracts to be discussed later.

These results suggest that British university research has little impact on British industry. Why then does the British government continue to finance university research? One possible reason is that university research only occasionally produces results of economic benefit but when it does the benefits are so large that they outweigh the total costs of all university research for several decades. An example of this kind in the present century would be the research that led to atomic power. A more fruitful source of such examples is the last half of the last century.

There is little doubt that German university research in organic chemistry, for example, provided the foundations for the German synthetic dyestuffs industry and subsequent advances in pharmaceuticals, synthetic rubber and plastics. Similarly the electrical industries can be seen as being based on nineteenth century academic research.

At the time of the First World War Britain realised that Germany had advanced industrially by using the results of scientific research, and in 1917 the Department of Scientific and Industrial Research was established. Since then, the British government has ploughed increasing amounts of money into scientific research in the belief that what was good for Germany in the last century should be good for Britain now.

But times have changed. Reliance on the German example does not seem to have been justified. One possible explanation is that the relationship between science (university research) and technology (industrial practice) has changed since the last century. To test this hypothesis, abstracts produced by the *Journal of the Society of Chemical Industry* were examined. For some eighty years, this Journal produced abstracts of the world's literature that might be of relevance to industrial chemists. Even in the last century, large teams of abstractors were used, reducing the possible bias of an individual. The abstracts were classified according to industrial subject matter, and those classes which might be considered to rest on organic chemistry were chosen for examination.

The original publications selected by the abstractors as being worth the attention of industrial chemists were consulted and wherever possible, institutional origins identified. Initially, the years 1884, 1917, 1935 and 1952 were examined but the difference in institutional origins between 1884 and 1917 was so great that the year 1899 was added to the investigation.

Table 2 shows the institutional sources of abstracts in randomly selected editions of the Journal for the given years. (A small proportion of abstracts in all years defied attempts to identify origins. The figures given are for identified sources.)

Teaching establishments are included under the category of university as are research laboratories and institutions attached to universities. The 'government' category includes Research Associations, government-financed industrial laboratories and military establishments.

Several of the abstracts were to patents some of which caused difficulties in the assignment of origins. Early patents usually give the name and pro-

Table 1 Institutional origins of literature cited in British industrial research

Origins	% of 102 ideas	% of 396 references	% of 452 abstracts (1952)
UK Industry	22	10	19
UK University	7	6	1
UK Government	19*	11	1
Foreign industry	40	40	68
Foreign university	3	21	5
Foreign government	9*	12	6

*Government and military combined

Table 2 Change with time of institutional sources of abstracts in *Journal of Society of Chemical Industry* for industrial areas connected with organic chemistry

Year of journal	**1884**	**1889**	**1917**	**1935**	**1952**
Institutional source	%	%	%	%	%
US industry	—	4.8	14.5	38.1	53.8
UK industry	8.8	17.3	6.2	9.3	19.0
European industry	23.5	44.7	52.4	24.1	13.6
Other industry	—	1.0	0.7	0.5	0.9
Total industry	**32.3**	**67.8**	**73.8**	**72.0**	**87.4**
US government	—	1.0	1.4	1.9	3.6
UK government	—	1.0	—	0.5	1.1
European government	5.9	1.9	2.1	3.4	1.3
Other government	—	1.0	2.1	0.5	1.1
Total government	**5.9**	**4.8**	**5.5**	**6.3**	**7.2**
US university	3.0	1.0	1.4	1.9	2.6
UK university	—	7.7	6.2	0.8	0.7
European university	58.8	18.7	13.1	15.3	0.2
Other university	—	—	—	3.7	2.0
Total university	**61.8**	**27.4**	**20.7**	**21.7**	**5.5**

Table 3 Change with time of institutional source of publications referred to by British industrial chemists in reviews of 'polyolefin' chemistry

Date of review	**1957**	**1961**	**1967**
	%	%	%
Institutional source	(n=28)	(n=71)	(n=102)
UK industry	3.5	12.0	12.0
US industry	41.5	46.0	} 69.5
European industry	5.0	7.0	
Total industry	**50.0**	**65.5**	**81.0**
UK university	—	—	2.0
US university	7.0	—	} 12.0
European university	43.0	28.0	
Total nuiversity	**50.0**	**28.0**	**14.0**
UK industry-university collaboration	—	—	3.0
US industry-university collaboration	—	6.5	} 2.0
European industry-university collaboration	—	—	
Total industry-university collaboration	**—**	**6.5**	**5.0**

fession of the inventor. In most cases the profession enabled a classification to be made, such as 'professor'—university; 'merchant'—industry. But descriptions such as 'gentleman' or 'subject of the Czar' had to remain unclassified unless the inventor could be identified from other sources. Papers by joint authors from different types of institutions were scored ½ each.

It can be seen from Table 2 that there has been a marked change in the relative importance of the institutional origins from European university (mainly German) to European industry and then to American industry as being the major contributors selected by the abstractors.

Although some of the change may be due to changes in abstractors or journal policy, the large decline in the relative importance of university publications from 61% in 1884 to 6% in 1952 and the steady growth in the importance of American industry from 0 in 1884 to 54% in 1953 can be assumed to be the result of a change in the relationship between university research in organic chemistry and those industries which use organic chemicals.

The data for 1952 are included in Table 1 for comparison with the studies previously mentioned. The data are based on an examination of 544 abstracts of which 59 could not be found, 6 had insufficient information and 27 were unclassifiable patents, leaving 452 identified origins. The three different studies give different percentage inputs but it should be noted that in all three studies:

- Foreign industry was the major source of inputs
- UK industry was the second most frequent source in two studies and the fourth most important in the other
- UK university was either the least important source or next to the least.

The dramatic change which has taken place since the days when German university research was providing results of direct relevance to the German dyestuffs industry may be explained by two alternative hypotheses:

(1) Industry has taken over its own research. The massive growth in industrial research since German industry employed teams of chemists to search for new dyes may explain the decline in apparent relevance of university research. However, university research has also grown enormously since the last century. (An interesting account[5] of the growth of British industrial research has been given by Sanderson.)

(2) A new branch of science is only useful in its early days. The early days of astronomy as a science were linked wth economically important attempts at improving navigation but astronomy has hardly been useful since then. (Even earlier, astronomy was used to maintain the power of priestly castes.) The early days of atomic power involved theoretical physicists; since then the theoretical physicists and the designers of nuclear power stations have moved further apart.

The early days of organic chemistry involved the production of new chemical substances and new ways of making them. Since then the university chemist has been more concerned with understanding the results of early research; the industrial chemist has been concerned with using the early knowledge and is not too interested in later theoretical developments.

One of the seven review articles referred to earlier was about 'polyolefins' and only 14 out of 102 identified references were to university research in spite of the fact that the present industrial importance of such materials as polypropylene started with the non-industrial research of Ziegler and Natta who may be considered to have founded if not a new branch of science, at least a new stem entitled stereospecific polymerisation.

It was decided, therefore, to test the above hypothesis by looking at earlier reviews of 'polyolefins' by industrial chemists. Table 3 shows that the relative importance of university contributions dropped from 50% in 1957 to 14% in 1967, although the absolute number of university contributions remained constant.

Another point of interest is that British industry began publishing items of interest to the reviewer before British universities. This was not because British universities ignored stereospecific polymerisation. It was because universities concentrated on the scientific problem of describing and explaining the mechanisms involved and the structure of the polymers produced whilst industry concentrated on obtaining manufacturing processes and improving properties such as light resistance. From a common origin, the discovery of stereospecific polymerisation, academics and industrialists have moved in different directions.

The relationship between university research and industry may well be a function of the degree of development of the area concerned. Once a new area has been established, the aim of science is to understand; the aim of technology is to make it work, and industry has been very successful at making things work without too much reliance on understanding.

Industry makes use of the trained manpower supplied by universities. It also uses new techniques such as chromatography, developed in universities. But the new products and processes of industry seem to depend on a combination of existing technological concepts, economic pressures and empirical research with scientific understanding not being very relevant.

This does not mean that university research is a waste of money; the situation may be changing. Concern about such matters as resource depletion, ecology, pollution, fire risk, health hazards and quality of working life coupled with the increasing scale of industrial operations may mean that industry will have to pay more attention to understanding what it is doing.

In the study of 84 innovations mentioned earlier, the only example of theoretical work in a British university assisting British industry was in the area of steel frames for building construction. A concern for human safety together with a shortage of steel led to the use of Baker's theory of plastic flow to design buildings which are safe but use less steel.

It could be that in the future, many sections of industry are going to require an increasing reliance upon theoretical research aimed at understanding, as the empirical approach, which has been so successful, joins the quest for economic growth as a thing of the past.

It would seem, therefore, that there are both macro and micro effects leading to changes in the relationship between science and technology.

At the micro level, the relevance of a particular part of science has depended on its degree of development. At the macro level, the relationship seems to move in cycles, with the first half of the nineteenth century involving little reliance upon scientific theory (although the scientific technique of methodical observation was made use of) the second half of the nineteenth century being characterised by a series of inputs from research concerned with exploring scientific problems, the first half of the present century being a triumph of industrial methodical empiricism and the future requiring an increasing dependence on understanding.

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2 Schmookler, J., *Invention and Economic Growth* (Harvard University Press, 1966).
3 Langrish, J., Gibbons, M., Evans, W. G., and Jevons, F. R., *Wealth from Knowledge* (Macmillan, London, 1972).
4 Langrish, J., *Chemistry in Britain*, **8**, 330 (1972).
5 Sanderson, M., *Science Studies*, **2**, 107 (1972).

international news

Improper plasmids?

by Eleanor Lawrence

A WORKING party under the chairmanship of Lord Ashby, Master of Clare College, Cambridge is being set up by the Advisory Board for the Research Councils to "make an authoritative assessment of the potential benefits and potential hazards of techniques which allow the experimental manipulation of the genetic composition of microorganisms".

At the same time the Medical Research Council (MRC) has made public the fact that they have asked their staff members not to embark on experiments in bacterial manipulation vetoed in the recent National Academy of Sciences (NAS) statement.

The letter circulated to directors of those MRC units which have the capacity to carry out work in this field asked that no experiments of type I and II in the NAS statement be undertaken in the near future until the working party has reported. This covers work on recombinant drug resistance plasmids that do not occur naturally, and the linking of animal virus DNA to plasmid DNA and its subsequent introduction and replication in a bacterial cell.

Directors were also asked not to initiate research on linking animal DNA to plasmid or bacterial DNA, which, according to the NAS statement, "should not be undertaken lightly." Experiments of this kind have already been carried out in the United States.

According to a spokesman for the MRC, the council supports no programmes actually involving research of the kind mentioned by the NAS, although the separate techniques are being studied in various laboratories. He estimated that about 50 laboratories in Britain have the capacity to carry out genetic manipulation of the sort vetoed by NAS, but that until now there had been a self-imposed holding back from this type of experiment, which has been technically possible for some time.

The establishment of a working party to clarify the issue is generally welcomed, as the part of the NAS statement referring to drug resistance plasmids is felt by some to be ambiguous; it could, for example, be interpreted as banning experiments necessary for important public health work. Other workers also feel that the ban on introducing animal genes into bacterial cells could hold up work on new ways of producing important substances such as insulin.

The working party will consist of "high-level scientists" and the Advisory Board for the Research Councils hopes to be able to announce the membership within the next two weeks. □