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「自由経済下での技術者の役割」

ケンブリッジ大学名誉教授

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Profile of Lecturer

Professor John F. Coales

1907 Born in Birmingham, England

1929 Bachelor of Arts in Mathematics and Physics, University of Cambridge

1929～1937 Scientific Officer, Department of Scientific Research and Experiment, Admiralty

1937～1946 Principal Scientific Officer, Admiralty

1952～1964 Assistant Director of Research, Lecturer, Reader at the Engineering Department, University of Cambridge

1965～1973 Professor, University of Cambridge

1974 • Professor Emeritus, University of Cambridge

1963～1966 President, International Federation of Automatic Control (IFAC)

1971～1972 President, Institution of Electrical Engineers

1973～1976 President, World Environment and Resources Council

In addition, Professor Coales has successively held the positions of chairman, director and fellow in various councils, committees and institutions of the electrical, electronic, automatic control, physic and agricultural engineering fields. He received his Doctorate in Technology honoris causa from the University of Loughborough and a Doctorate in Engineering honoris causa from the University of Sheffield. He was decorated with Commander of the Order of the British Empire.

● Publications

Automatic and Remote Control, Proceedings of the First IFAC International Congress, Moscow 1960 (Editor)
Original papers in Scientific and Technical Journals on Radio, Direction-finding, Radar, Magnetic Amplifiers, Information Theory, Automation, Control Theory, Instrumentation and Computation, Engineering Education and Training, etc.

講師略歴

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1907 英国バーミンガム生れ

1929 ケンブリッジ大学 数学・物理学士

1929～1937 海軍本部 科学士官

1937～1946 海軍本部 科学士官長

1952～1964 ケンブリッジ大学 工学部 研究部長・講師

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1974～ ケンブリッジ大学 名誉教授

1963～1966 IFAC(国際自動制御連盟)会長

1971～1972 IEE(電気学会)会長

1973～1976 世界環境資源審議会 会長

この他、電気・電子・自動制御・物理・農業工学等幅広い分野で、審議会・学会・研究所等の議長・役員・フェローを歴任。ローグボルグ大学並びにシェフィールド大学から名誉工学博士号、また大英勲章第3位を受章する。

●著書

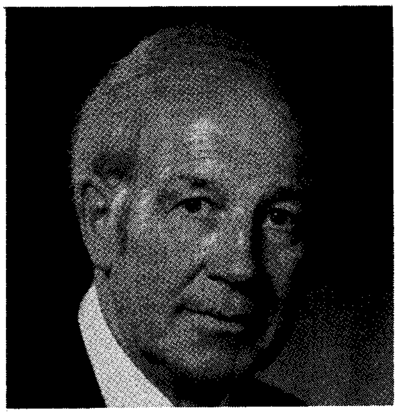
IFAC第一回国際会議(1960年 モスクワ)会議録“自動遠隔制御”を編集
サイエンティフィック・アンド・テクニカルジャーナルへの発表論文
無線方位測定、電波探知法、磁気増幅器、情報理論、オートメーション、制御理論、計装計算、工学教育および研修、等

このレポートは昭和57年11月17日、ホテル・オークラにおいて行なわれた1982年度本田賞授与式の記念講演の要旨をまとめたものです。

THE ROLE OF THE ENGINEER IN A FREE ECONOMY

Lecture at the Conferring Ceremony on the 17th of November 1982, in Tokyo

Professor John F. Coales
The Winner of The Honda Prize 1982



Twelve years ago in 1970 the total population of the world was about 3.6 billion and 2/3rds or 2.4 billion people in the Third World had a standard of living only 1/12th of that in the industrially developed countries. At that time it was recommended by the United Nations that each developed country should give 1% of its gross domestic product (GDP) in aid to the "Third World," that is the less developed countries. This 1% would have been approximately 60 billion US dollars which was then approximately 5% of the total gross domestic product (GDP) of the less developed countries. From the then available statistics relating rates of increase of productivity and capital investment, one might have expected a 5% per annum rise in the gross domestic product (GDP) of the less developed countries and if this went on for 15 years then the average gross domestic product per capita (gdp per capita) would double, providing the population did not also increase. Even so after this 15 years, i.e. by 1980, the standard of living as measured by gdp, (not to be confused with quality of life but fairly closely related to it), would still have been no more than one-sixth of that in the developed world.

Unfortunately the amount of aid provided by the developed countries fell far short of 1% of GDP but nevertheless the GDP of the less developed countries has risen by 5% per annum, presumably due to investment of savings within the less developed countries. However the population in the less developed countries increased on average by about 3.0% per annum, and so, although the GDP of the less developed countries have, on average, risen by about 5% per annum between 1970 and 1980, the gdp per capita in them has only risen on average by 2% per annum. From 1976–78 official aid to the less developed countries only averaged about 20 billion dollars a year but there was an additional 30 billion dollars of capital flowing to the less developed countries from private organizations in the West making nearly 50 billion dollars a year for capital development in accordance with Table 1. There are a number of paradoxes met when one tries to estimate the increase in GDP for a given investment of capital. These are discussed in the appendix.

TABLE 1

Average Flow of Funds from Developed Countries
to Less Developed Countries 1976 – 78

Outflow of Official Economic Aid:–	$ mn.	% GDP
From non-communist developed countries	15,951	0.32
From communist developed countries	3,614	0.23
Total official economic aid	19,565	0.30
Private capital flows (from non-communist countries)	29,610	0.59
Official general flows	3,769	0.08
	52,944	0.81

It therefore appears that in less developed countries an increase in GDP rather greater than 10% of the capital aid provided can be expected but even so, taking into account population increase, the annual increase in gdp per capita is unlikely to exceed about 5% per annum. If maintained this should enable the less developed countries to increase their gdp per capita to 40% of that of the developed countries in about 35 years provided their population does not increase too rapidly.

Analysis of statistics available in the industrially developed countries, gathered over the past quarter century, leads to the conclusion that if the gdp per capita in the less developed countries is to be quadrupled then the proportion of their populations employed in the "productive industries" must rise to at least 8%. In no way can the average gdp in the Third World be quadrupled by importation of consumer goods from the developed world and, although in the early years much of the capital equipment will have to be manufactured in the developed world, eventually each region, if not each individual country, will have to be mainly self-supporting. There may be geographical variations in the mix of industries and services but on average a figure of at least 8% will have to be attained.

In recent years thanks to statistics obtained in various industrially developed countries, and particularly some obtained in the U.K. census of 1971, it has been possible to demonstrate with considerable certainty that only those industries in which at least 3% of the workforce have been qualified engineers and scientists, have been able to expand or, in other words, continue to improve their efficiency sufficiently to combat competition. Since the world's natural resources are clearly limited and are continually becoming more difficult to exploit and utilize, this increasing efficiency is essential if the capital investment envisaged above is to be effective. It is now generally accepted that for each 120 employees in the productive industries there will need to be on average four qualified engineers and 16 technicians in accordance with Table 2.

TABLE 2

1	Manager
1	Leading engineer
3	Engineers and applied scientists
4	Technician engineers
12	Technicians
20	Craftsmen
20	Clerical and administrative grades
59	Semi-skilled and unskilled
120	

Taking these various considerations into account and bearing in mind the magnitude of the task and the absolute necessity of continuing growth in developing countries, if the quality of life in them is ever to become what we in the developed countries would deem even acceptable, four conditions can be seen to be absolutely essential:

1. that population increase be limited to 1 or 2% per annum
2. that capital investment be at least $25 per annum per head of population at 1980 prices (see below)
3. that 8% of the population be employed in the "productive industries" as soon as possible
4. that in the "productive industries" at least 3 1/3% of those employed are qualified engineers or applied scientists, and 12 1/2% are qualified technicians.

I have not used the term "technologists" because in some countries this term is used for higher technicians. In the calculations applied scientists working in the productive industries have been treated as engineers and in what follows the term engineers includes them.

The term "productive industries" is used to include all manufacturing industries, whether producing capital or consumer goods, public utilities such as power, communications and transport and building and construction but not services such as medical care, education, domestic and catering or the armed services.

The first requirement in less developed countries is clearly for improved agriculture but for this to be successful in many areas irrigation is necessary and in all better transport and communications are essential. History demonstrates that as agriculture becomes more efficient population migrates from the rural areas into towns and cities hoping to find work in manufacturing industries and the increased services that are required by the more prosperous inhabitants. It has been estimated that by the turn of the century at least 100 more conurbations the size of Chicago will have arisen. Unfortunately in almost every developing country the hopes of those who leave the rural areas are not realized because there is no work for them in the cities and more often than not neither is there any housing. This only serves to emphasize the need not only for capital investment to provide housing and public utilities essential for city life but also manufacturing industry to provide employment on the one hand and to create the wealth required to finance the capital investment and services on the other. All of these activities require engineers in the approximate proportions set out in Table 2 and as agriculture becomes more efficient the working population inevitably has to be transferred into the productive industries and services such as administration, health care and education.

Some want to turn the clock back and dismantle the developed countries so that all may live in the Arcadia of a neolithic or rural culture but, even if it were desirable, with the population of the world inevitably rising to 6 billion by the year 2000 it is now impossible. In 1725 the population of Britain was about 6 million and, thanks to improved hygiene and medicine, it doubled in 25 years, i.e. 3% per annum which was less than in many parts of the developing world today. It was only by improving the efficiency in agriculture and developing "automation" in milling and textiles that this increased population could be fed and clothed and so, since Necessity is the Mother of Invention, the Industrial Revolution was born. This in turn led to the flight from the country to the town and the consequent poverty and degradation similar to that seen in most big cities today. The population is now 56 million and although we are in the middle of a severe recession with more than 3 million unemployed, no one is starving and everyone can have a roof over his head, piped water, electricity, medical attention and education, comforts which are considered to be the minimum to which anyone now born into the world has an inalienable right.

In the developed world these facilities are only possible because there has been enormous investment over two and a half centuries so that the accumulated capital per head of population is at least $10,000 (at 1980 prices). This suggests that the $500 or so per head of population which may be invested in the less developed countries by the developed countries in the next 30 to 40 years will have to be greatly supplemented from the less developed countries own resources. Even if people were prepared to go back to the rural type of life of the 18th century with no electricity, television and motor cars it would be quite impossible to feed and clothe anything approaching 50 million people living in the British Isles unless millions of acres of mountainous country were brought into cultivation, or food factories built on a vast scale either of which would require capital works of enormous size for many years.

Certainly life of reasonable quality is much less costly in real terms in a rural community than in a big city but the quality has been greatly enhanced by electricity, radio, television and modern transport which has brought education, entertainment, culture and mobility within the reach of all. Maybe it would be both more pleasant and less costly if we could all live in relatively small communities rather than large conurbations. Perhaps someday we shall be able to rearrange our affairs so that we can do this but for many decades we are stuck with large towns and large conurbations, all of which require massive engineering projects to make them even habitable. The problem of unemployment and poverty in large cities is economic rather than technological but whatever the solution is it will inevitably increase the demand for capital equipment, consumer goods and services, all of which involve engineering. For these reasons the conditions 3 and 4 set out above cannot possibly be underestimated and lead to the conclusion that by the year 2000 A.D. at least 16 million engineers will be required in the "productive industries" throughout the world with probably an additional 8 million in education, government and the defence services. It is difficult to estimate the total number of qualified engineers, (qualified applied scientists are taken as engineers in this context to simplify the calculations), in the world at the present time but it is unlikely to exceed 10 million so an annual increase of at least 5% per annum is needed, which would not be impossible if the education and training facilities for some 2 million engineering students were available now. It is possible that in the developed third of the world there may be nearly $1^1/_2$ million places available giving some 400,000 graduates a year but in the other two thirds it is unlikely that there are more than 200,000. Even when a stable equilibrium is reached an annual output of at least 800,000 will be needed since this would require an average working life of 30 years, which is unlikely to be exceeded, and by that time the less developed countries will need to be largely self-supporting so that at least 500,000 of these should be educated and trained in them. On average this would require a 5% increase each year in the output of engineers in the less developed countries but in many of them the number at present being trained is so small that it will have to be increased very much more rapidly.

In the British Commonwealth, plans are being considered to increase the number of engineering graduates by the use of programmed learning and case studies in university courses, but there will still remain the problem of providing adequate facilities for practical training and experience in countries which as yet have very little manufacturing industry. Just as at present most of the engineering in the Third World is carried out by engineers educated in developed countries so also is the training of most engineers from less developed countries obtained in other places. This is most unsatisfactory because the conditions pertaining in less developed countries differ widely and the problems that arise are very different from those experienced in developed countries. For this reason it is very important that in each less developed country there shall be leading engineers with experience in that country who can solve these unexpected problems as they arise and bring major engineering projects to a successful conclusion.

Experience has shown that modern technology cannot usually be transferred from a highly developed to a less developed country without modification particularly since in the poorer less developed country resources are likely to be scarce and it is all important that the most efficient and economic solutions be found. More often than not this calls for the greatest ingenuity and engineering skill, so it is essential that we consider not only the number of engineers the world will need in the 21st century but, even more importantly, their ability.

It was for this reason that in 1977 the Commonwealth Board for Engineering Education and Training adopted a definition of a higher category of professional engineer than that normally recognized throughout the world as being fully qualified or chartered. This is the category of leading engineer or engineering leader into which we believe at least one in four of all qualified engineers must graduate by virtue of their inherent ability and experience. These are the engineers who can be relied upon to bring an engineering project to a successful conclusion in reasonable time and without unnecessary expense. The leading engineer must ensure that the solution is the most economic for the purpose for which it is required, that the bridge is big enough for future traffic but not too big, that the power station is fuelled in the most economic way for the region in which it is to operate, that the television station can give a satisfactory service to the area it is to serve or the computer system is large enough for its immediate purposes but can be quite easily extended to meet the expected future needs. He must ensure that it will operate without undue maintenance in the environment in which it will be installed, can be manufactured and installed as economically as possible by the time it is required, and when operating will not only be as inexpensive as possible but will not in any way endanger its environment or those who have to operate and maintain it.

These considerations must be taken into account in any engineering work large or small, whether it be a suspension bridge or a solar panel, a communications network or a pocket calculator. It is only in degree that they differ and they always require engineering judgement and relatively wise decisions have to be taken. In general, experience can only be widened by working on a number of different jobs in varying circumstances and this inevitably takes time. On graduation the young engineer can only have very limited experience and it has also been found that experience is only effective in developing the engineer's critical faculties when it is gained working on the job. Whenever possible a young engineer should work with a senior from whose greater experience he can learn. Under a senior's guidance he should be responsible for one or two smaller tasks which he should be able to bring to a successful conclusion. This master-pupil relationship is very important in the early years and the young engineer who either cannot or does not get the opportunity to learn from more experienced engineers is unlikely to become a leader. Usually the young engineer having completed a relatively simple task will move on to a more complicated one whether it be in development, design, installation, operation or maintenance and hopefully by the time he is 30 years old he will have successfully completed several different jobs in varying circumstances.

He should then have broadened his experience beyond the narrow specialization of his first few years and, provided his judgement is sound and his ability high, be ready to take his place as a leading engineer and be put in charge of a small but important project. It is usual then for the leading engineer to take charge of bigger and more important projects involving a wider range of engineering and management techniques, for which he may have to direct a group of engineers of very different experience and expertise. In this way the leading engineer gradually broadens his experience so that he can be trusted to make the right decisions based on the advice of his supporting staff. If an engineer is to fulfill his potential, it is essential that throughout his life he takes every opportunity to increase his technical competence by study, by widening his practical experience and, above all, by endeavouring to obtain the best solution to the problem in hand. It is therefore just as much to his advantage as to his client's or employer's when he strives for perfection and lets nothing deter him. This calls for professional integrity and moral courage of the highest quality from the start of his career, and if he does not acquire these attributes during his education and training (*formation* as the French call it) he probably never will. The influence of a good master can make all the difference in this respect and is one of the reasons why the master-pupil relationship in the training period is so important.

In all professions integrity is an essential requirement in its members because they are only engaged to undertake work which their clients cannot do themselves. The client has therefore no means of knowing whether or not the doctor, lawyer or engineer is doing his best for him and can only rely on his integrity as a professional man. In the case of the doctor or surgeon it is quite certainly a case of "your life in his hands" but in the case of the engineer it may mean the safety of thousands or even the well-being of millions in *his* hands. There is just no room for complacency and the engineer must always be on the alert whether it be in development, design, installation, operation or maintenance. Catastrophe or disaster is never far away and we cannot foretell with any precision either the time or nature of it, so the engineer must expect the unexpected and, because more often than not the fault when it occurs he will not have experienced before, he must in a sense be familiar with the unfamiliar.

It has been said that the engineering profession differs from the others because most of its members are employed by corporate bodies rather than by individual clients but although this may affect the nature of the relationship it in no way reduces the need for these qualities of integrity and assiduity. As in medicine the success of an engineering project depends on getting every detail right as well as the system as a whole. Having planned the project so that it not only meets the client's specification of performance but can be made by the time required at the lowest possible cost, the leading engineer must watch over the details even when they lie outside his experience and expertise. As has been said in another connection this requires "inspiration, application and dedication" with a determination of purpose that most men will only apply to their own selfish ends; only the missionary can do it for the glory of God. The professional man usually gives his best for his client partly for the fee he will earn and partly in the hope that, if successful, his work will get known and he will become more and more respected and be able to earn higher fees, but the individual relationship with the client undoubtedly plays a part in bringing out the best in most professional men, which is just as well since only well qualified members of his profession can judge when an engineer has been negligent. It is for this reason that in Britain we believe that each profession must be self regulating and responsible for its own disciplinary procedures.

When an engineer is employed in a large organization the simple relationship with the client becomes complex and confused because the client is now the organization but the engineer has a moral responsibility for the safety and well being of the customers of his employers and these interests may be conflicting. Further, it is now accepted that a professional engineer must always keep in mind the national interests and the effect on the environment in all he does, and these may run quite counter to the intentions of his employers. Professional integrity demands that if he is called on to do something which would violate these principles he points it out to his superiors just as he should to his client when working for an individual. For several reasons the individual client is much more easily persuaded of the need to change his specification and, in any case, if he cannot be persuaded the engineer will have other clients and can much more easily refuse to do the work for him. If as a fulltime employee he cannot persuade the management to do what is right the honest engineer has no alternative but to leave the firm, a very difficult decision indeed and one which could result in *lesser* men "cutting corners".

This does not mean that there must always be conflict between the engineer and the entrepreneur. That would be most unjustly denigrating the entrepreneur. No! the successful engineer must be entrepreneurial because, if he is not, his best work may never be exploited and will benefit nobody. If it is exploited successfully and he profits by it, he is fortunate but, if he is unsuccessful, he must carefully consider the reasons and try again.

To many people the role of the engineer in the large organization appears to be different from that of the consulting engineer but this is a misconception that must be strenuously resisted. Because failure to get the details right may cause a major disaster even the most junior engineer must display in some degree courageous integrity and not merely do what he is told by his superiors. The great danger is that if as a young graduate he goes into a large organization he gets to look upon himself as just another employee, there to do what he is told and frightened to argue with his superiors lest he miss promotion or even lose his job. Most young men want to do their best for their employers and in a junior position it is very difficult to look beyond the confines of the establishment in which one works and in which one is paid. This is one of the most important reasons why the engineering profession must hold together and instill into all its members the essential need for professional integrity. As I have already indicated, in the 21st century the world will need vast numbers of engineers and if they fail in their duty there will be terrible disasters.

Engineers must therefore live and work without fear or favour of any man and they must be educated and trained in such a way that they instinctively believe that in whatever they do only the best can suffice. In a free and technologically developed economy there are opportunities for this to pertain provided the independence of the professions can be maintained. The greatest danger to the professions in a capitalist society is that the love of money leads to corruption or, worse, to bribery but I believe that personal relationships with the clients on the one hand and with professional colleagues on the other are the greatest safeguards. In a controlled economy these have to be replaced by a sense of working for the community as a whole but one cannot help feeling that the frustration of working for a large and usually faceless organization tends to dull the edge of integrity, particularly among lesser mortals. In the less developed countries there is the added problem that more often than not training of engineers is inadequate and it is almost impossible to get any breadth of experience in the early years. Further, the great shortage of able and experienced engineers results in engineers being appointed to relatively high positions in government departments very young and after this they will probably get no further practical experience.

If we are to be successful in developing technology to save the world from penury in the 21st century we must develop the engineering profession to serve the human race with the zeal of missionaries and this can only be done if we work together and support each other irrespective of colour, race or creed or indeed of ideological belief. As Lord Hailsham, the Lord High Chancellor of England, said some ten years ago at the centenary celebrations of my Institution "I do not know if the professions need the world but certainly the world needs the professions. Professions of the World unite."

APPENDIX

A Note on the ratio of capital invested to increase in GDP

Estimation of the expected increase in GDP for a given amount of capital invested involves a number of paradoxes. In Britain between 1957 and 1966 the GDP rose from £22,000mn to £30,000mn an average of 3.5% per annum while the average annual investment averaged 17% of GDP. This gives an increase in GDP of 20% of the value of capital invested which agrees with Klein's factor for the industrially developed countries from 1950 to 1974 but does not take into account inflation. On the other hand when the GDP of the U.K. was £40,000mn it was estimated that the accumulated invested capital in the U.K. was approximately £400,000mn of which fixed assets represented about £200,000mn and the other £200,000mn represented intangible investment such as in education and health care. This would imply a figure of 10% but would be 20% if only the fixed assets were taken into account. For this and other reasons I arrived at a ratio of 10 to 1 in 1970.

Klein at the Wharton Institute, Philadelphia has arrived at a figure of 20% of GDP reinvested per annum (p.a.) in the non-communist developed countries during the years 1950–74 but assumes a 10% p.a. depreciation of capital. In this period GDP rose 2.89 times or just over 3½% p.a. He gives the accumulated capital as $2,356 bn in 1950 with GDP as $853 bn, a ratio of rather less than 3 and the annual increase in capital as only about 10% p.a. taking into account depreciation at 10% p.a. In real terms (1970 = 100) the increase is also 3½% p.a. In the less developed countries from 1960–1974 GDP rose 2.25 times or on average 7% p.a. While accumulated capital rose only 43% or just over 3% p.a. the ratio of accumulated capital to GDP dropped from 4.4 to 2.8. He believes that the proportion of GDP invested has risen from 15% p.a. to 23% p.a. This gives that the rise in GDP has been approximately one third of the savings.

Another paradox is that manufacturing industry expects to turn over the capital employed at least once a year implying a 1 : 1 relationship. However this takes no account of the capital invested in education and health care nor in housing, transport and communications in which we know the ratio is high. Further, manufacturing industry only contributes a relatively small fraction, 28%, of the GDP. In the U.K. in 1979 the GDP was £189,702mn and gross fixed capital formation £36,646mn, 18% of GDP, of which construction was £10,237mn or 30%. Between 1970 and 1979 GDP increased on average 2.3% and since 1979 there has been no real increase in manufacturing output although there has quite certainly been some capital investment so this points to a 10 : 1 ratio on average rather than 5 : 1.

Klein uses a depreciation rate of 10% for the developed countries and 5% for the less developed countries which is no doubt why he arrives at such a low figure for accumulated capital. This is certainly much too high a rate for buildings, roads and bridges, coal mines and most heavy industry. Even in manufacturing industry in Britain there are many machines more than 100 years old and the average age is well over 20 years. It is probable therefore that the real rate of depreciation is not more than 3% p.a., just about the average rate of inflation in the period, the years 1957–66, in which case the effect of depreciation can be neglected.

Taking all these considerations into account it would appear that the 10 : 1 ratio of capital invested to increase in GDP is probably as good an estimate as any, both for industrially developed countries and less developed countries.