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The requirements for engineering education in South Africa

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SYNOPSIS

The skills differential between manpower supply and demand is due to deeply rooted socio- and politico-educational misconceptions that can be remedied only by a concerted cooperative effort on the part of the general public, the State, organized industry, organized engineering, and engineering education. This will require the general public to recognize that the reasons for the shortages in engineering manpower should be regarded as critical.

Public perceptions of engineering, of the vocational and educational prospects in engineering, and of the skills required are poor. The spectrum of engineering vocations, the corresponding function profiles, the interaction between the vocations and the relative proportions of the vocations in the engineering team are in general not adequately appreciated. The recruitment and training of students and teaching staff, teaching facilities, educational curricula, practical training, qualifications, professional registration, and financing are aspects of engineering education that should be brought to the attention of all concerned.

In addition, the educational curricula for the various vocations need to be specified clearly and definitively if the overall mission of engineering education is to be properly appreciated. The uncertainties between university and technikon education and the pursuant vocations need to be resolved. This can be done only by defining the respective curricula in terms of the mental skills and scientific techniques required.

The remedial actions with regard to the rationalization of engineering education comprise informing of the public; establishment of an active political lobby; revision of existing education policy; rationalization of existing educational infrastructure; promotion, development, and guidance of engineering student intake; financing of engineering education; accelerated creation of new employment opportunities; and monitoring of the supply and demand of high-level manpower. The parties required to initiate these remedial actions are various State departments and corporations involved in engineering and industry, various departments of education, the Directorate of Technology of the Department of Trade and Industry, organized engineering education, organized engineering, organized industry, and the Human Sciences Research Council. Only if these interest groups actively initiate the various actions under the coordinated guidance of organized engineering will the required results be achieved.

The South African Engineering Association has proposed a comprehensive programme as strategy to solving the problem, and has obtained broad consensus from various State departments, organized engineering education and research, and the private sector. A joint venture between the Foundation for Research Development, the South African Engineering Association, and organized industry has been charged by the State President with the task of launching the programme.

SAMEVATTING

Die vaardigheidsverskil tussen die aanbod van en vraag na mannekrag is toe te skryf aan diep gewortelde sosiaal- en politiese-opvoedkundige wanopvattings wat net reggestel kan word deur 'n gesamentlike poging van die kant van die algemene publiek, die Staat, die georganiseerde bedryf, die georganiseerde ingenieurswese, en ingenieursonderrig. Die algemene publiek sal moet insien dat die redes vir die tekorte in ingenieursmannekrag as kritiek beskou moet word.

Die openbare opvattings van ingenieurswese, die beroeps- en opvoedkundige vooruitsigte in ingenieurswese, en die vereiste vaardighede is swak. Die spektrum van ingenieursberoepe, die ooreenstemmende funksieprofiele, die wisselwerking tussen die beroepe, en die relatiewe verhoudings van die beroepe in die ingenieurspan word oor die algemeen nie behoorlik besef nie. Die werwing en opleiding van studente en onderrigpersoneel, onderrigfasiliteite, onderwysleerplanne, praktiese opleiding, kwalifikasies, professionele registrasie en finansiering is aspekte van ingenieursonderrig wat onder die aandag van alle betrokkenes gebring behoort te word.

Verder moet die onderwysleerplanne vir die verskillende beroepe duidelik en definitief omskryf word om mense die algehele missie van ingenieursonderrig behoorlik te laat begryp. Die onsekerhede wat betref universiteits- en technikononderwys en die beroepe wat daaruit voortspruit, moet opgeklaar word. Dit kan slegs gedoen word deur die onderskeie leerplanne te omskryf in terme van die denkvaardighede en wetenskaplike tegnieke wat nodig is.

Die remediërende aksies wat betref die rasionalisering van ingenieursonderrig behels die inligting van die publiek; die daarstelling van aktiewe politieke steunwerwing, hersiening van die bestaande onderwysbeleid; die rasionalisering van die bestaande onderwysinfrastruktuur; bevordering, ontwikkeling en leiding wat betref die inname van ingenieurstudente; finansiering van ingenieursonderrig; versnelde skepping van nuwe werkgeleenthede, en die monitering van die vraag na en aanbod van hoëvlakse mannekrag. Die instansies betrokke by hierdie remediërende stappe moet doen, is die onderskeie staatsdepartemente en korporasies betrokke by ingenieurswese en die bedryf, die verskillende onderwysdepartemente, die Direktoraat van Tegnologie van die Departement van Handel en Nywerheid, die georganiseerde ingenieursonderrig, die georganiseerde ingenieurswese, die georganiseerde nywerheid, en die Raad vir Geesteswetenskaplike Navorsing. Die verlangde resultate sal net bereik word as hierdie belangegroepe die verskillende aksies onder die gekoördineerde leiding van die georganiseerde ingenieurswese loods.

Die Suid-Afrikaanse Ingenieursvereniging het 'n omvattende program as strategie vir die oplossing van die probleem voorgestel en die algemene instemming van verskeie staatsdepartemente, die georganiseerde ingenieursonderrig en -navorsing, en die private sektor verkry. Die Staatspresident het die taak om die program van stapel te stuur opgedra aan 'n gesamentlike onderneming tussen die Stigting vir Navorsingsontwikkeling, die Suid-Afrikaanse Ingenieursvereniging, en die georganiseerde bedryf.

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INTRODUCTION

Skills Differential

It has long been known that the supply of skilled manpower does not satifsy the demand, either in terms of the number of persons or in terms of the type of skills. Several authoritative commissions have investigated the education and manpower requirements[1], and the State has indeed promulgated legislation to address the problem. Nevertheless, the actions taken have not been as effective as expected. Not only has the mismatch between supply and demand not been curbed, but it has been increasing continually.

The object of this paper is to consider some of the reasons for the lack of progress, to propose a strategy of action, and to review developments in this regard.

The skills differential is due to deficiencies in both the supply and demand sides of the equation. On the supply side, the differential arises from the facts that the greater proportion of students pursue an academic rather than a vocational education, and that most students pursue an education that will lead to employment in the income-consuming, rather than in the income-generating, sectors of the economy. On the demand side, the differential is rooted in the predilection to develop and exploit natural, in preference to human, resources.

Terminology

The practical arts are here referred to collectively as *engineering* or *technology*, and comprise the field of endeavour in which ingenuity is exploited for the purpose of providing practically useful contrivances or utilities. The recognized vocations are those of the engineer, technologist, technician, and artisan. The generic terms *engineering* and *technology* are used interchangeably in the paper with regard to the entire field of practical endeavour, and should not be taken as referring exclusively to the vocations of the engineer and of the technologist respectively.

High-level manpower comprises professional and semi-professional personnel, technicians, managers, and executives with at least two years of formal post-matric training[2]. *Middle-level manpower* comprises personnel with formal job-specific training over a prescribed period after Standard 7 or 8. *Low-level manpower* comprises unskilled personnel with an education lower than Standard 7.

SOCIO- AND POLITICO-EDUCATIONAL CONSIDERATIONS

The incompatibility between the supply and demand of skilled personnel is a problem rooted in socio- and politico-educational misconceptions and shortcomings, some of which are generally held, and some of which have found official expression in instituted education. These deficiencies form part of the educational culture and can be remedied only by the cooperation of all concerned. The general public has the most important contribution to make in this regard.

The distinction between general and instituted lapses in educational concept and practice is not clear in all instances. An attempt is accordingly made in what follows to present these separately with the view to defining appropriate remedial action.

General Lapses in Educational Concept and Practice

Mental Faculties

Mental faculties, memory, and analytic- and synthetic-thinking skills are exploited in this order in the educational system. Teaching has, as a result, become answer-orientated, and education an exercise in spoon feeding and rote learning.

Synthetic thinking is the most important mental faculty, and without it progress cannot be made. 'Synthesis is the action in thought of proceeding from cause to effect or from laws or principles to their consequences'[3]. Synthetic thinking is inductive in character, and as such relies on intermittent recourse to analysis. Bronowski[4] likens synthetic ability to the moulding action of the hand, and analytic ability to the splitting action of the hand axe. He consequently ranks analytic ability higher than synthetic ability, the former being the fundamental faculty of the theoretical scientist, and is perfectly correct in this regard. Synthetic thinking, however, plays the dominant role in technology as the basis of ingenuity.

The neglect of the basic sciences, which enable the associated powers of reason and logical deduction to be developed, is directly responsible for the poor synthetic-thinking abilities of pupils and students alike. A vicious cycle is at work in which low synthetic-thinking ability thwarts its own remedy—the pursuit of the basic sciences. Low synthetic-thinking ability consequently feeds on itself in a downward spiral.

Analytic- and synthetic-thinking skills are, in addition to general knowledge and career-specific skills, fundamental attributes for the proper functioning of high-level manpower.

Work Ethic

Competition for employment is non-existent in South Africa, and this is the most important reason for the poor work ethic among Whites. It has been caused directly by the White domination of high-level manpower and employment[5], and is the price paid for the privilege of job reservation. As a result, careers are not chosen with sufficiently exhaustive consideration of the attributes of the individual and the particular skills and knowledge required, nor with regard to prospective employment opportunities. It is as if the career is not associated at all with the stuff of employment or work, and as if job satisfaction is not appreciated as the reward for physical and mental effort.

Indecision

Career selection is often postponed because of an inability or unwillingness to take a committed decision. The process of choosing a career should start in primary school, and should be considered constantly by parent, child, and teacher throughout secondary schooling. A final period in which the career is decided upon in earnest should start about two years before a scholar completes school, which, together with proper career guidance, will resolve the problem. Lack of decisiveness and commitment are undesirable traits and should in all instances be discouraged, particularly with regard to management positions.

Job Security

The security offered by employment in a particular industry or sector of the economy is a fundamental criterion in the selection of a career, provided it is not misconstrued. The criterion is not how secure the job will be irrespective of the occupant's assiduity, but rather whether the job offers sufficient opportunities for the occupant to ensure his security by dint of his own effort. Job security is seated in the individual and is entirely within his control. The public sector is unfortunately too often regarded as a safe haven for the wrong reasons. As much as any other sector in the economy, it requires the calibre of staff who assure themselves of their own security.

Curriculum Bias

As a manifestation of low synthetic-thinking skills, matriculants show a propensity for social sciences at the expense of basic sciences. This is especially true of Black pupils, of whom only 500 out of the 25 000 who gained university exemption in 1989 had studied mathematics[6].

University students also show an overwhelmingly greater preference for the social sciences and commercial fields of study. In 1985, 4113 out of 33 526 graduates qualified in engineering and science, and of these a most disconcerting total of only 485 degrees were conferred on Blacks, Coloureds, and Asians[7].

The same predominant preferences for the social sciences and commercial fields of study apply to technikon students. In 1987, 1967 out of 6080 graduates qualified in engineering and computer science, of whom an insignificant number were Black, Coloured, and Asian.

The subjects taken at school and the performance in these determine the tertiary field of study and career choice[8]. The jobs that the Blacks will require in ever-increasing numbers will to a large extent be available in industry, but they are going to have to take basic sciences in very significantly greater numbers at school. This problem also faces Whites, Coloureds, and Asians, but not to the same extent.

These skewed subject preferences lead to manpower surpluses in the income-consuming sectors of the economy, and to manpower shortages in the income-generating sectors.

Institution Bias

The choice of educational institution and the type of career skill eventually mastered are, like subject preferences, influenced indirectly by low synthetic-thinking ability: 80 per cent of high-school pupils follow academic streams, and 20 per cent career streams. The proportions should instead be at least 40:60 in terms of the demands of the employment market[9].

Four times as many students enrol at universities as at technikons. Among Blacks, universities attract ten times more students than technikons[7]. Instead of 10:1, the ratio should be 1:4. The section of the nation for which there is the biggest need for career education shows the least preference for it.

One of the fundamental reasons for the mismatch is that the Blacks are not looking to education for a career, but as an access to social upliftment and recognition. The manpower shortages and Black employment aspirations will remain unsatisfied until this conception changes. There are equally fundamental socio-educational misconceptions underlying the gross imbalances in the vocational education of Whites, Coloureds, and Asians, which will have to be addressed in solving the concomitant manpower crisis.

Education Bias

A biased emphasis on educational status by parents, teachers, and employers alike has resulted in the pursuit of education largely for the sake of the qualification, and not for the inherent knowledge and skills. Neither the job opportunity nor the job satisfaction concomitant with the qualification are considered in the selection of a career. The career that may be required and suited to the individual, and for which there will be a demand, should be established at the start. Only then should the relevant education and training be identified and pursued. The reward will be knowledge and skills that are useful to the individual and to society.

Employers in general still regard a traditional academic education as a measure of good character[10]. This situation has remained unchallenged because of the suppressive effect of the domination of management positions by Whites on the growth in demand for high-level manpower.

MacFarlane[11] reported in 1988 that public-service organizations were generally hesitant to appoint technologists, many town councils did not employ them at all, smaller local-government institutions employed technologists in positions ranging from technicians to town engineers, building contractors were not interested in qualifications as such, and consulting engineers accepted technologists most readily and provided the most satisfactory employment.

Engineering Misconceived

The general public has a poor perception of the essential aspects of engineering, the vocational and educational prospects in engineering, and the skills and knowledge required. The lack of clarity between university and technikon engineering education and the specific purpose of each are major contributory factors in this regard. The basic reason, however, is that engineering lacks popular appeal and, as a non-glamorous pursuit, has never inspired an inquisitiveness about itself.

Formal Shortfalls in Educational Concept and Practice

Performance Criteria

Two of the major reasons for students' preoccupation with answers and the tendency towards rote learning are the excessive emphasis that has been placed on academic performance and the measurement of such performance in terms of grade point averages[10]. Status and rewards, particularly bursaries and scholarships, are heavily dependent at secondary and tertiary level on these measurements. Academic indices are poor predictors of career performance, ironically particularly so in respect of higher academic qualifications[8]. The yearly wave of matric distinction mania and the exaggerated press coverage afforded it are an aggravating manifestation of the problem.

Career Guidance

The guidance provided at school in the selection of careers is completely inadequate[10] and, by contributing (albeit by default) to the skills differential, causes immeasurable damage to the development of the country. It is one of the most urgent problems that should be addressed without delay.

Location and Viability of Institutions

As a result of politico-economic developments, many institutions of tertiary eduction are inappropriately located. Such an institution should be located close to the student source, close to the market that will absorb its graduates, or close to the industry that will derive benefit from it and support it. In addition, the establishment of such institutions should be justified on economic grounds only. This will largely reduce ethnicity as a criterion, avoid unnecessary duplication of facilities, foster cooperation between neighbouring institutions, and obviate dilution of scarce teaching staff. Further, the efficient utilization of campus accommodation can be improved greatly by the holding of more than one academic session per day.

Black universities and technikons are generally located away from the major concentration of potential students. Some of the established White universities are likewise located far from the base student source, from the industries that can be looked upon for support, and from future places of employment for their graduates. Existing facilities obviously cannot be closed, but should be phased into a new dispensation in terms of a long-term plan.

Subsidized Financing

The State does not accord any priority or provide any incentive to manpower training at tertiary level, through either legislation or preferential financing. The subsidy formulae stimulate indiscriminate growth in student numbers[8]. Educational institutions are given an incentive to satisfy the demand for training without regard to the academic bias inherent in the demand, thereby enhancing it. The institutions cannot afford to influence the demand away from academic toward career objectives, have no incentives to raise entrance qualifications, and cannot afford to pursue excellence through specialization.

The form of the cutbacks in State financing in recent years has resulted in tertiary-education institutions adopting policies of low growth at a time when the country can ill afford a reduced rate in the training of high-level manpower[7]. This has aggravated a long-standing decline in the number of students pursuing tertiary education compared with the number of matric pupils. In the high-technology era that the country is about to enter, the knowledge intrinsic to high-level manpower will contribute more to industrial growth than the mere availability of labour. Yet between 1969 and 1985 the student population at residential universities and technikons grew only by half of what it should have been compared with the number of matriculants[12].

The universities receive from the State about 4 per cent more towards their fixed costs, and about 33 per cent more towards their current expenses, than the technikons[2]. All the tertiary institutions are forced to raise additional funding from the private sector, which, owing to the number of institutions and the limited geographic spread of major potential donors in the Pretoria–Witwatersrand–Vereeniging area, has given rise to an undignified rivalry among fund-raising organizations that is detrimental to the cause. The universities enjoy established positions in this regard, whereas the technikons have to find their feet as novices in an environment that is traditionally indifferent to career-orientated education. These disparities in financing do not enable the technikons to absorb more students at a stage when the proportion of students at the two institutions should be reversed.

In-service Training

Experiential training is an important element of the co-operative education programme followed by technikons. Industry is inclined to short-term gains and, as a result, allows the number of in-service training posts to fluctuate with the vicissitudes of the economy. This does not contribute to the security nor to the status of vocationally oriented education.

The large State corporations traditionally provided in-service training facilities far in excess of their own requirements, and in so doing made an important contribution to industry[7]. In the wake of the current drive towards privatization, these training opportunities are being cut back in order to improve cost efficiency. Instead, the in-service training facilities should be retained, if not expanded, in the interest of the economy, and improvements in cost efficiency should be sought elsewhere in these organizations.

Unclear Education Objectives

The differences in university and technikon education are not clearly defined. Engineering involves a range of activities from the mental conception of a practically beneficial project or device to its physical execution. For this purpose, it requires a spectrum of mental, judgemental, management, experiential, and manual skills, together with basic and applied scientific techniques. The main vocational categories covering the considerable width of skills and scientific techniques comprise engineers, technologists, technicians, and artisans. The education and training of manpower in the different categories is unique owing to the specific composition of skills and techniques involved in each. At tertiary level, technikon and university education are not viable alternatives for each other: both fulfil indispensable specific aspects of the engineering spectrum.

CRITICAL SHORTAGES IN ENGINEERING MANPOWER

The manpower deficiencies are so extensive, intrinsic, and complex that neither the State nor private enterprise, on their own or together, can solve the problem. The general public has to be involved in the process. The problem can be solved only if the public identifies with it and if a national cooperative effort is mustered in its cause.

Technology is the foundation of socio-economc activity insofar as it enables the tasks involved in the provision of an appropriate livelihood to be done and, in addition, to be done faster, more efficiently, less wastefully, and more conveniently. The dependence on technology and associated high-level manpower, which will accompany the current drive for political reform and economic growth, can be illustrated by a consideration of the following demographic, anthropographic, and social aspects.

Population Growth and Urbanization

The population is expected to increase from 32 million in 1985, to 45 million in 2000, and to 70 million in 2020. This will be accompanied by urbanization and by a massive shift of the Blacks from a low-income to an industrial economy. The urban population is expected to grow from 16 million in 1985, to 36 million in 2000, and to 63 million in 2020. In terms of housing alone, this will require that 1000 units, complete with the attendant roads, transport, services, and waste-disposal infrastructure, should be built every day to the end of the century[14].

Of the population, 70 per cent is excluded from the Eskom network. Catching up with the backlog is a considerable technical and administrative problem, which is small in comparison with the future problem of providing the growing numbers of Black families with electricity. Urban Blacks consume 10 per cent of the water that Whites do. An upliftment of their quality of life will be associated with a vastly increased demand for water, which will bring about its own set of technological challenges in view of the fact that the largest concentrations of people will not be close to natural sources of water of adequate capacity.

Productivity

The productivity of a system is determined by two factors: the comprehensiveness and balance with regard to the technological expertise of the manpower structure, and the efficient application by manpower of itself to the task. Production capacity can be increased considerably by improvements in the appropriate utilization of manpower[15], but it can be increased only marginally by improvements in labour efficiency.

The relatively low productivity in industry can therefore be obviated by the adoption of a technology-oriented, instead of labour-oriented, approach to manpower[16]. The approach to manpower may historically have been labour-oriented by design, and it will remain much the same unless a very significant change in attitude is adopted to focus attention on vocational education and, more specifically, on such education and training in technology.

The natural resources available to any nation are demarcated. The projected massive socio-economic and socio-political pressures for increased production can therefore be met only by the exploitation of manpower in the technologically most advanced manner. Only by maximizing all the potential production output can the future demands for goods and services be satisfied.

Improvements in economic prosperity, and the correlation between such prosperity and advances in technological education, are clearly illustrated by the commercial successes achieved in recent times by South Korea and Taiwan[17].

Standard of Living

The Blacks are looking to education with unabated expectation as a means of overcoming their third-world standard of living. This will satisfy their aspirations until it is realized that the only permanent solution is to have access to an own adequate source of income, for which purpose education has to be directed to the pursuant vocation. High-level manpower shortages in industry will be the future mainspring for career opportunities. Unless technological education and training are pursued with consummate dedication, South Africa will become impoverished like Albania, Burma, and Cuba[17].

Strategic Resource Replaced

Human endeavour has historically experienced three phases: an agricultural phase lasting three thousand years up to the seventeenth century, an industrial phase lasting three hundred years into the present era, and an entrepreneurial phase, which started after the Second World War[18,19]. Capital was the strategic resource in the industrial society; information, knowledge, and creativity are the key resources in the entrepreneurial society. Without education and skills, especially the creative kind, people can neither become part of this society nor contribute to it. Unless the larger proportion of the nation is adequately educated and skilled, the distending forces will not allow a contented and harmonious existence to be found for all.

In the absence of State interference and competition, entrepreneurial society tends to spawn a multiplicity of low-cost small manufacturing businesses supplying specialized services and sub-components. Such businesses flourish on technology and high-level manpower and, in both highly and less developed countries, have proved to be major sources of employment. In the U.S.A., manufacturing businesses with fewer than twenty workers were responsible for 56 per cent of the employment growth during the period 1976 to 1982. In Taiwan, 90 per cent of businesses falling within the small to medium range provide 70 per cent of the employment[13].

Consumption Patterns

The patterns of Black consumer spending have changed in recent years, and will continue to do so in future. Food and beverage sales are growing at 8 to 10 per cent per year[14]. Substantial growth will occur in sales of luxury goods, cars, houses, household appliances, education, insurance, pension funds, and recreation as Black affluence rises. To fund their spending aspirations, Blacks are lobbying for a distribution of wealth. However, at an average gross domestic product of R5700 per head, there is not much wealth to be distributed and, if the wealth is distributed as popularly called for, it will lead to the impoverishment of Whites, instead of an upliftment of Blacks. Instead, the objective should be to expand the existing wealth by raising personal income through adequate employment opportunities. As indicated elsewhere, such employment opportunities will become available primarily through education and training in technology.

Economic Growth

Major structural changes have occurred in the economy. The trend is away from agriculture and mining towards manufacturing, construction, and services. However, a change in economic structure alone will not be sufficient: economic growth will have to be stimulated significantly. Personal income will not change at the present economic growth rate of 2,4 per cent[14]. A growth rate of 5,4 per cent will satisfy the demand for employment in the formal sector, but the informal sector will not take off strongly enough to uproot poverty unless an economic growth rate in excess of 10 per cent is achieved; hence, the emphasis on technological education and training.

KEY ASPECTS OF ENGINEERING

Engineering is the process of exploiting ingenuity for the production of practically beneficial systems or contrivances, for which it relies on human judgement and experience to harness scientific law and principle. It is a multi-phase process, ranging from the ingenious excogitation to the practical implementation of such systems or contrivances. Each of the phases consists of specific proportions of mental skills and scientific techniques. Key aspects of the acquisition and practice of the skills and the underlying knowledge of scientific techniques can be summarized as follows.

Engineering Activity Spectrum

Engineering encompasses a spectrum of activities comprising mental conception: feasibility evaluation; design; specification; planning; resourcing and procurement of equipment, material, and labour; and physical execution. Every activity requires mental, judgemental, experiential, management, and manual skills, as well as basic, applied, and social scientific techniques, to varying degrees. The spectrum of activities can be divided conveniently into

TABLE I

COMPOSITION AND RELATIVE WEIGHTING OF MENTAL SKILLS AND SCIENTIFIC TECHNIQUES PROPOSED TO BE ACQUIRED IN VARIOUS ENGINEERING VOCATIONS DURING TERTIARY EDUCATION AND TRAINING

Vocational category	Institution and age range	Skills or techniques	Semester								Score	Remarks
			1	2	3	4	5	6	7	8		
Engineer	University 18–22 (4 years)	Analytic thinking	6	6	6	7					25	Sophisticated
		Synthetic thinking					6	6	6	7	25	Sophisticated
		Experiential	–	–	–	–	–	–	–	–	–	Nil
		Judgemental	–	–	–	–	–	–	–	–	–	Acquired during Pr Eng pupilage
		Management and organizational	–	–	–	–	–	–	–	–	–	Acquired in practice
		Manual	–	–	–	–	–	–	–	–	–	Nil
		Basic scientific	6	6	6	7	–	–	–	–	25	Comprehensive
		Applied scientific	–	–	–	–	6	6	6	7	25	Comprehensive
		Social scientific	–	–	–	–	–	–	–	–	–	Acquired in practice
	Total score										100	
Technologist	Technikon 18–22 (4 years)	Analytic thinking	6	6	7	–	–	–	–	–	19	Modest
		Synthetic thinking	–	–	–	6	–	6	–	7	19	Modest
		Experiential	–	–	–	–	12		12		24	Comprehensive
		Judgemental	–	–	–	–	–	–	–	–	–	Acquired during Pr Tech Eng pupilage
		Management and organizational	–	–	–	–	–	–	–	–	–	Acquired in practice
		Manual	–	–	–	–	–	–	–	–	–	Nil
		Basic scientific	6	6	7	–	–	–	–	–	19	Modest
		Applied scientific	–	–	–	6	–	6	–	7	19	Modest
		Social scientific	–	–	–	–	–	–	–	–	–	Acquired in practice
	Total score										100	

four main vocations, each representing a practically useful and recognized combination of skills and techniques: engineers, technologists, technicians, and artisans.

The compositions of skills and techniques in the various vocations are illustrated conceptually in Table I. The weightings are given for comparative purposes only and should not be interpreted literally. The experiential and judgemental skills referred to in the table are defined later, together with discussions on the post-educational practical training required for the various vocations. Specialized engineering education and training options are not considered in this paper.

It is evident that the education and training programmes are category specific because of the particular combinations of skills and techniques. The existing lack of clarity between the various educational curricula and vocations arises from the fact that the differences are defined in terms of relative educational level and employment environment. The definition of the various vocations in terms of the underlying skills and techniques provides the only way in which the differences between university and technikon training and the pursuant vocations can be clearly distinguished and in terms of which the mission of each institution can be expressed definitively.

It is important to observe that the various skills and techniques are not acquired on a progessively increasing basis in terms of the period of education particular to the vocation. The analytic-thinking skills are generally acquired in conjunction with a study of the basic scientific techniques, whereas the synthetic-thinking skills are developed most effectively by design assignments involving applications of both basic and applied scientific techniques.

TABLE I (Continued)

COMPOSITION AND RELATIVE WEIGHTING OF MENTAL SKILLS AND SCIENTIFIC TECHNIQUES PROPOSED TO BE ACQUIRED IN VARIOUS ENGINEERING VOCATIONS DURING TERTIARY EDUCATION AND TRAINING

Vocational category	Institution and age range	Skills or techniques	Semester										Score	Remarks
			1	2	3	4	5	6	7	8	9	10		
Technician	Technikon 18–21 (3 years)	Analytic thinking	–	6	–	6	–	–	–	–	–	–	12	Limited
		Synthetic thinking	–	–	–	–	–	6	–	–	–	–	6	Very limited
		Experiential	–	–	6	–	6	–	–	–	–	–	12	Limited
		Judgemental	–	–	–	–	–	–	–	–	–	–	–	Nil
		Management and organizational	–	–	–	–	–	–	–	–	–	–	–	Acquired in practice
		Manual	6	–	–	–	–	–	–	–	–	–	6	Very limited
		Basic scientific	–	6	–	6	–	–	–	–	–	–	12	Limited
		Applied scientific	–	–	–	–	–	6	–	–	–	–	6	Very limited
		Social scientific	–	–	–	–	–	–	–	–	–	–	–	Acquired in practice
	Total score												54	
Artisan	Technical college and college and apprenticeship 15–20 (5 years)	Analytic thinking	–	–	–	–	–	–	1	1	1	1	4	Very limited
		Synthetic thinking	–	–	–	–	–	–	–	–	1	1	2	Minimal
		Experiential	–	–	–	–	–	–	–	–	–	–	–	Nil
		Judgemental	–	–	–	–	–	–	–	–	–	–	–	Nil
		Management and organizational	–	–	–	–	–	–	–	–	–	–	–	Acquired in employment
		Manual	1	1	1	2	2	2	4	4	4	4	25	Sophisticated
		Basic scientific	–	–	–	–	–	–	1	1	1	1	4	Very limited
		Applied scientific	–	–	–	–	–	–	–	–	1	1	2	Minimal
		Social scientific	–	–	–	–	–	–	–	–	–	–	–	Acquired in employment
	Total score												37	

The sophisticated analytic-thinking skills and the comprehensive basic scientific techniques that an engineer requires are acquired in principle during the first two years of university study, and the sophisticated synthetic-thinking skills and comprehensive appropriate applied scientific techniques during the last two years of study.

The technologist requires modest analytic- and synthetic-thinking skills, comprehensive experiential skills, and modest basic and appropriate applied scientific skills. It is proposed that his analytic-thinking skills and basic scientific techniques be acquired during the first three semesters at technikon, his synthetic-thinking skills and appropriate applied scientific techniques in the fourth, sixth, and eighth semesters, and his experiential skills in the fifth and seventh semesters.

The technician requires limited analytic-thinking skills, experiential skills, and basic scientific techniques, and very limited synthetic-thinking skills, manual skills, and applied scientific techniques. It is proposed that his analytic-thinking skills and basic scientific techniques should be acquired in the second and fourth semesters, his synthetic-thinking skills and applied scientific techniques in the sixth semester, his manual skills in the first semester, and his experiential skills in the third and fifth semesters.

The artisan requires very limited analytic-thinking skills and basic scientific techniques, minimal synthetic-thinking skills and applied scientific techniques, and sophisticated manual skills. The educational programme shown for the artisan in Table I is schematic, and is given for comparative purposes only. It may not represent the actual situation, which at this stage is not proposed to be changed.

It is evident that the engineer and the technologist can, in terms of the proposed educational programmes, share the first three semesters and change from one vocational stream to the other. After the first three semesters, the education becomes career-specific, and conversions from the one to the other institution are impossible. The two vocational directions would, despite these differences, be of exactly the same educational stature.

The technologist and the technician cannot share their course work extensively owing to the intermittent effect of the experiential training periods in the technician's programme. As a result, conversions between these two streams will not be time-effective unless the technologist's programme is revised at the expense of maximum convertibility with the university programme for engineers. An upgrading in the convertibility between the technologist's and the technician's programmes will have the additional undesirable effect of bringing the technologist's experiential training periods forward in the course.

Engineering Function Profiles

The educational curriculum of the engineer makes him suitable for the mental conceptualization and global-design phases of technology. As such, his main function is to ensure, by calculation and judgement, that scientific law is comprehensively and essentially accounted for. The engineer is the legal custodian of public interest with regard to the practical application of currently available scientific knowledge and attracts a commercial liability in this respect.

The educational curriculum of the technologist makes him suitable for the bulk of the detail design and systematic planning of the execution phases of technology. The technologist is specifically required to ensure, by calculation and experience, that a project can be executed practically and productively. He is the legal custodian of public interest with regard to detailed practical executability. The technologist is legally entitled to undertake work appropriate to his education and experiential training for his own account and, as such, attracts a commercial liability.

As the risk profile in this regard is as yet unknown, the premium structure for insurance against professional liability is uncertain. The uncertainties arise from misunderstandings that 'a professional engineer' will vouch for the competence and care of the professional technologist's work, and from a lack of clarity of the limitations of the technologist's expertise. The technologist will not rise to his rightful stature unless these misconceptions are clarified. The speed of the process will depend on the rate and extent to which technologists in private practice seek professional indemnity insurance.

The educational curriculum of the technician is of a general nature, and makes him suitable for the provision of the execution infrastructure, plant, equipment, tools, and instruments. He is also capable of procuring materials, controlling stores, establishing the artisan corps, and supervising detail jobbing aspects and maintenance programmes. The technician is specifically required to ensure that the project is carried out, and that it is carried out on time and productively. He is the legal custodian of public interest in these regards, and may undertake work independently for his own account, in which instance he attracts a commercial liability. The risk profile of the technician is completely untested in this regard.

The education and training of the artisan equip him specifically with the manual skills required for the actual execution of the work with the use of sophisticated tools and equipment.

Engineering Team

As indicated, the considerable range of skills involved in engineering, gives rise to a number of interrelated vocational categories. There is no other field of human endeavour in which the collaboration of substantial teams of people is so extensively relied on as in engineering. The range of skills and width of scientific knowledge are so extensive that no one person can provide all the necessary expertise across the full engineering spectrum. Perhaps the most important aspect of the engineering team is the extent to which members from different vocations rely on one another's judgement for the successful implementation and commissioning of a project.

Only by realizing the rightful roles of the various vocations in the overall engineering team, and by providing for balanced inputs from them, can productivity be maximized and quality be optimally assured. Various authorities have investigated the extent to which engineers are involved in doing the work of technologists and technicians[20-22]. They have found that, on average, 25 to 42 per cent of an engineer's work can be done by technologists and technicians, and that 20 per cent can be done by administrative staff. The waste of manpower and the loss in productivity are obvious. The inverse situation, in which artisans or technicians are involved in the functions of technologists or engineers, is equally wasteful with regard to productivity.

Engineering Posts Structure

The ratio of technicians to scientists and engineers is on average 3,25 to 1,0 in developed (first-world) countries, and 13,5 to 1,0 in developing (third-world) countries[7]. The corresponding ratio for South Africa is 0,8 to 1,0, i.e. lower than the average for the developing countries. Of the one million matriculants who will be leaving school in the next generation, approximately 150 000 and 200 000 will enter the universities and technikons per year, respectively 1,67 and 10 times more than at present.

In 1985, 4113 engineers and scientists graduated from universities and, in 1987, 1967 technologists, technicians, and computer scientists graduated from technikons. The application of projected increases in student intake to these figures indicates that, in the year 2020, 7000 students will graduate annually in engineering and science from universities, and about 20 000 in engineering and computer science from technikons—a reversal in relative proportion from 0,8:1,0 to the desired ratio of about 3,0:1,0. However, this will be achieved only if concertedly planned and implemented.

KEY ASPECTS OF ENGINEERING EDUCATION

Engineering education and training will be rationalized only if all the relevant aspects are addressed on an integrated basis in terms of manpower demand. The essential aspects involved can be summarized briefly as follows.

Recruitment and Preparation of Students

Career Guidance

Relevant career instruction and guidance services should be instituted at primary and secondary schools. If education is exclusively career-oriented, instruction in possible careers and the determination of appropriate career choices should be readily to hand in the educational institution.

Career-objective education also requires that the future employer be introduced at secondary-school level. Career instructional advice is generally on offer throughout the country by members of the community qualified in virtually every field of endeavour. Instituted education has, however, persistently refused to make use of this invaluable source of qualified information, and pupils are therefore deprived of a width of knowledge and insight that neither the formal teaching corps nor any individual can provide.

The final career choice should be made with the assistance of a professional vocational-guidance expert and subject to the most sophisticated aptitude determinations available. The spectrum of personal attributes should be considered with regard to career activities and prospects for the entire life of the career, and not only with regard to the period that follows immediately upon completion of the prescribed education and training.

Teaching of Basic Sciences

A study of the basic sciences at school develops the powers of reasoning and logical deduction. The analytic- and synthetic-thinking skills so acquired are invaluable attributes for high-level manpower, irrespective of the particular career choice. Among Whites, the bias against basic sciences is due to ill-informed preference and, among Blacks, Asians, and Coloureds, it is largely due to a disadvantaged environment and to a lack of adequate teaching facilities.

The Programme for Technological Careers, Protec, is a privately funded career-development programme for Black students who show a potential in mathematics and science[23]. Participants are selected from Standard 8 and are exposed to a programme lasting seventy days per year for 3 to 7 years, including Saturday and vacation schools, field trips, work experiences, and post-school financial support. The organization grew from 67 students in 1982 to over 5000 in 1990. Of the 625 matric candidates in 1989, 76 per cent passed, compared with the national average of 42 per cent, and 42 per cent obtained matriculation exemption, compared with the national average of 10 per cent. Also, of the candidates in mathematics and science, 32 per cent obtained matriculation exemption, compared with the national average of 0,4 per cent. The programme has demonstrated over a considerable period that educational achievement is far and away due to the quality of the teaching.

The Protec programme is an experiment on a sample of the population. Its achievements should be extended within instituted education and by substantial contributions by industry in the form of the auxiliary educational centres initiated by Sasol at Zamdela and eMbalenhle for the purpose of upgrading the teaching standards in mathematics and physical science in the schools local to Sasol[24]. The importance of the basic sciences should be impressed upon pupils of all population groups throughout their secondary schooling. The necessary good-quality teaching staff and facilities should be provided for this purpose as a matter of national urgency by the State and industry. Campaigns should be launched on a regular basis to inform the general public of the need and purpose in this regard.

Entrance Standards

Entrance standards are a basic instrument to ensuring the desired enrolment proportions between universities and technikons. The university standard should accordingly be raised. The entrance standard for technikons is appropriate in that it allows the potential manpower to be exploited maximally over a wider range of personal abilities within the context of a graded qualification system.

The quality of education is not assured by entrance standards alone, but is determined to a greater extent by an appropriate career choice and competent teaching.

Cooperative Employment

Organized employment should be more formally involved with the cooperative employment component of technikon education. Permanent posts should be established by employers on the undertaking by technikons that they will ensure continued occupation of such posts. The technikons will require additional staff to support this function, but it will improve the quality of the experiential component immeasurably. It will assure organized employment of the relevance of the education, and the technikons of the commitment of organized employment.

The main advantage is that students will be educated with specific employment opportunities in mind. If these are not forthcoming in sufficient numbers, appropriate action will need to be taken.

Recruitment and Training of Teaching Staff

Remuneration

The shortage in engineering teaching staff at tertiary level, and in basic-science teachers at secondary level, is super-critical, and is due mainly to inadequate remuneration and insufficient financial support for collaborative research. The perception of an academic career is so poor that an insufficient number of graduates consider pursuing doctoral degrees; the disconcerting result is that, instead of the augmentation of the reservoir of academic talent, it is gradually depleted. The various ways in which this complex problem can be solved have been detailed by the Joint Committee on Engineering Education, Training and Recruitment of SAVI and SPE[25]. The most important aspect of any solution is that it should be permanent and not subject to the vicissitudes of the economy.

Good-quality engineering teachers at tertiary level, and good-quality basic-science teachers at secondary level, can be provided in the numbers required only if market-related salaries are offered. This will necessarily bring about differential remunerative structures within instituted education, which may cause resentment and may be met with resistance but, difficult as it may seem, will have to be accepted.

An aspect that cannot be discouraged strongly enough is that teaching staff at tertiary level augment their income by means of consulting work. Nothing can distract more from the purpose and quality of tertiary education than inappropriate consulting activity. The little consulting work that is required to keep the individual in touch with practice cannot contribute significantly to his income in any event.

Role of Research

The quality of engineering education is closely related to the research that is undertaken generally in the educational institution and specifically by the individual member of staff. This applies to both universities and technikons.

The proposed clarification in curricula at the two tertiary institutions, together with the proposed upgrading in technikon qualifications, will promote a greater interchangeability of staff between universities and technikons, and will expand the range of research topics that can be undertaken by technikon staff.

It is essential for the development of synthetic-thinking skills that the teaching staff at universities should be engaged in innovative or basic research appropriate to the capital resources of the country as a developing economy. The teaching staff at technikons may likewise be engaged in such innovative research, but should at least actively pursue applied research.

The distinction that Alberts[26] draws between quantum and incremental innovative research is of particular importance in this regard. Both types of research are basic because of their inherent innovative character, and it is as a result of this aspect that such research stimulates synthetic thinking. The applied research referred to in the context of technikons involves the development of the processes, systems, tools, and equipment required in the production of end products or utilities.

The industrial robot affords a good example of the differences in basic and applied research. The conceptualization of the robot and the development of its basic systems represent the research undertaken at a university, whereas the development of a specific robot for a particular application represents the research undertaken at a technikon. It is evident that the applied researcher can be involved at master's or doctoral level in this regard. Criteria similar to those applicable to university degrees would apply. Familiarity with the development of the production process would be the criterion for an M Tech degree, and an original contribution to production or execution technology would satisfy the requirements for a D Tech degree.

Centres of Excellence

Centres of excellence are the cradles for the research necessary to ensure the quality of engineering education. In addition to affording members of staff ready access to an active research environment, they also serve to attract contract research as a worthy additional source of income for both the institution and the individual.

Accommodation

Architecture and Equipment

The buildings in which educational institutions are accommodated should be as simple as functionality would allow. No expense should be incurred in respect of unnecessarily luxurious aesthetics or finishes. Above all, the institutions should be propertly equipped and provided with adequate library facilities.

Number and Location of Institutions

The establishment and location of new tertiary institutions must be economically justified and, in addition, should at least be close to the student source, employment market, or supporting industry. This will promote the principle that one attends the tertiary educational institution in one's home city and, conversely, that the institution in one's home city can accommodate one. Only those courses that satisfy these criteria should be provided for in any institution. Existing institutions should be phased into a new dispensation, and may result in having to be opened to population groups not previously provided for.

Engineering Curricula

Engineering curricula can be structured either in terms of fundamental engineering phenomena, i.e. energy, materials, systems, and cybernetics; or in terms of classical engineering subjects, e.g. structural engineering, geotechnics, and hydraulics; or in terms of engineering products or utilities such as roads, railways, and dams.

The first two structures are appropriate to the education of engineers in which the emphasis is on the assurance of scientific and applied scientific law, and on the conceptualization and global-design phases of technology. The third structure is suitable for the education of technologists in which the emphasis is on the provision of end products or utilities, and on the detail design and standardized harnessing of scientific-and-applied-scientific-principle phases of technology.

In order to remain relevant, university engineering curricula have generally developed a trend towards the third structure without a concomitant relaxation in entrance standard. University curricula should be redirected towards the proper objective of training engineers as defined, which will at the same time require that the entrance standards should be raised as already proposed.

Technikon curricula should be extended as proposed earlier to an equivalent total academic term of three years in conjunction with an experiential training period of one year, of which the content should be more concentrated and the standard raised. The additional time for academic training should be devoted largely to increasing the basic-science content. This may result in a temporary reduction in the enrolment of students at universities, but will be accompanied by an increase in students at technikons. Overall, the market demand will be satisfied more appropriately, and the quality of engineering education will improve across the full spectrum. As the economy grows, the intake of engineering students at universities will again increase. The universities should not resist such a development, provided the subsidy formula is revised in such a way that they are not adversely affected by a reduction in student numbers.

The proposed extension of the academic portion of the technologist's curriculum is in line in principle with the observation that the term of an engineer's education at university is a year too short in comparison with international standards[27].

Practical Training

Judgemental skill enables the engineer to confidently apply his knowledge of basic and applied scientific techniques to the conceptualization and global design of novel engineering systems and contrivances. It relates to the experience that the engineer has of the application and exploitation of scientific law or principle. The newly conceptualized system or contrivance to which the engineer wishes to apply a particular scientific law may be completely different in size and character from that in respect of which he gained the relevant experience.

Experiential skill enables the technologist to confidently apply his knowledge of basic and applied scientific techniques to the provision of standardized engineering products and utilities. It relates to the technologist's experience in the implementation of a particular or similar product or utility.

Both these skills, judgemental and experiential,, are acquired during periods of practical training. The primary practical-training period of the technologist runs concurrently with his academic education to ensure that the link between intellectual understanding and practical execution is of sufficient strength. The development of this link is of particular importance to the technologist in view of the modest development of his synthetic-thinking skills. This does not detract from the stature of the technologist's training. The particular approach on which it is based is a perfectly equivalent alternative, which has the additional economically desirable advantage of producing a person useful to industry in a shorter period of time.

It is evident that the six-year training period required for the National Diploma of Technology defeats this object, which is another reason why the technikon curriculum should be so amended that a degree can be awarded after the fourth year of study.

In the case of the engineer, the link between intellectual understanding and practical execution is equally important but, in view of the sophisticated development of his synthetic-thinking skills, it can be developed informally during the period of pupilage towards professional registration.

Qualifications

Peer recognition is the incentive to achievement and the crown to self-esteem. It is embodied in the prestige of the qualification awarded on the successful completion of a prescribed curriculum. The graded structure of qualifications offered by the technikons allows recognized exits at various levels of training in recognition of variations in individual ability and market demand, and is admirable in this regard. However, none of the qualifications carries sufficient prestige to defeat the institutional and educational biases referred to earlier. The problem will be solved by the introduction of a Bachelor's Degree in Engineering to replace the National Higher Diploma in Engineering. The extension of the academic term at technikons in this regard to three years, and an increase in the basic-science content as proposed, will render the course worthy of a degree.

The introduction of a degree at technikons will immeasurably improve the self-esteem of their graduates, and will enable technikon students to upgrade their education progessively within the home institution. Indecisiveness and a lack of work ethic in the late teens should not be allowed to close career opportunities for life. The introduction of a degree at technikons will give capable young people a chance to adjust an inappropriate career choice in good time, with great improvements in their self-esteem and benefits to the country.

A lack of self-esteem and a feeling of inadequacy in comparison with their university counterparts seem to be reasonably common among technikon engineering graduates. The engineering fraternity and organized employment aggravate the situation by not according due recognition to the technikon graduate. This is a grave threat to the economy in that lack of self-esteem gravely impairs a worker's productivity. Future generations of technikon graduates cannot be sent into the market place in the considerable numbers expected with this disadvantage.

Consideration should also be given to awarding higher degrees at master's and doctoral level, as already proposed elsewhere. The degrees awarded by universities and technikons can be easily distinguished by the suffixes Eng and Tech Eng respectively. A word of caution should be sounded, however. If technikons are to award degrees, they should offer degrees only in disciplines where the courses are of worthy academic duration and content. Overlaps with universities will be minimal, and should be obviated by mutual agreement. Notwithstanding, the extensive array of vocational directions offered at technikons at least warrants such a consideration.

Professional Registration

Professional registration is the final step in the education and practical training of the engineer or technologist, which accords him the privilege of practising his skills independently and for his own account. This places a considerable onus on the individual as a custodian of public interest. The work of both the engineer and the technologist is of such a stature that it cannot be properly executed unless it is based on a sound academic education to which the prestige of the qualification attests. Engineers and technologists should be encouraged to apply for registration at the earliest possible time and, on being successful, should appropriately advocate their professional status by using the titles Pr Eng and Pr Tech Eng respectively.

Despite the proposed differences in academic curricula and practical training programmes for engineers and technologists, the engineer will, on a proper reading of the Professional Engineer's Act, be entitled to assume responsibility for the technologist's work. The technologist will, however, not be entitled to assume responsibility for the engineer's work. This poses an anomaly that can be resolved only once greater clarity has been established with regard to the limits of the various engineering vocations. The complexity of the problem is illustrated by observing that, on a similar proper reading of the Act, the engineer is not entitled to assume responsibility for the technician's work and *vice versa*. The anomalous situation between the engineer and the technologist should, however, not detract from the status of the technologist provided the educational status of the technologist is not inferior to that of the engineer, which would be assured by the proposed re-curriculation of the technikon programme. The engineer would, at most, be the first among equals.

Finances

Funding Criteria

Shortages in funds at tertiary level mostly affect the remuneration packages of teaching staff, support for collaborative research, and facilities and equipment. At secondary level, it affects the availability of teachers in the basic sciences, as well as their salaries. The solution to the problem should primarily ensure reliable funding that is not subject to the vicissitudes of the economy. Consideration should also be given to incentive remuneration to ensure high-quality teaching, especially with regard to the backlog in the basic sciences at secondary level. Research at tertiary level should become goal-oriented and the funding provided accordingly. The achievements of research workers should, just as in private practice, be subject to competitive performance.

Funding Sources

The subsidy formulae should be revised to emphasize priorities for, firstly, engineering education at tertiary institutions; secondly, engineering education at technikons; and, thirdly, economically viable educational institutions close to the student source and close to the employment source. The salaries of teachers at secondary level should also be revised to provide an incentive for teaching the basic sciences and to counter competitive salaries in the private sector. Such preferential remuneration should, however, be conditional on achievement. Funding from organized industry and employment sources should be based on a national strategy that will ensure donors of the effective use of their contributions. Donors from organized industry and employment sources can mostly be obtained with reasonable ease, provided the goals are clearly defined and regular feed-back is given of progress. The uncontrolled and preferential funding of tertiary institutions by organized industry and employment sources should be resolved.

The importance of vocational education and the study of the basic sciences can be emphasized most effectively by an across-the-board levy system. In addition, considerable financial assistance and capital investment in Black education is potentially available internationally. However, it will not be readily forthcoming until the country's politically adverse image has been changed. All of these sources should be identified and actively exploited as part of the proposed national strategic plan on education.

PLAN OF ACTION

Because of its complexity, the mismatch between manpower supply and demand can be resolved only by the adoption of a definitive plan of action in terms of specific tasks, the various interests involved, the organizational structure required, and a pro-active course of implementation. Accordingly, detailed proposals in these regards are submitted in this section, together with a review of the steps that have already been taken.

Tasks Identified

The following specific tasks can be identified for the rationalization of engineering education and training and for the creation of employment opportunities:

- Information of the public and establishment of a political lobby
- Development of a national strategy on technology
- Revision and expansion of the existing education policy
- Rationalization and expansion of the existing educational and training infrastructure
- Promotion, development, and guidance of engineering-student intake
- Financing of engineering education and training
- Creation of new employment opportunities
- Monitoring of high-level manpower supply and demand.

The general public needs to be informed and convinced of the general lapses in educational concept and practice, of the reasons why the shortages in technological manpower are considered to be critical, of the essential aspects of engineering, of the vocational and educational prospects of engineering, and of the basic skills required.

Much of the action needs to be taken by State departments and quasi-State organizations, the mandates for which are in general defined by the State and the broader political representative infrastructure. The State, its advisory bodies, and its political representatives should accordingly be informed in the same way as suggested for the general public. The envisaged lobby, especially with regard to the broader political representation, will not be effective unless undertaken on a full-time permanent basis.

The existing education policy needs to be revised and expanded with regard to performance criteria, career guidance, criteria for the economically optimum exploitation of existing tertiary-educational institutions and for the establishment of new institutions, entrance standards for universities and technikons, subsidized financing of tertiary engineering education, importance of the study of basic sciences at school, improved teaching of the basic sciences, recruitment and training of basic-science teachers, differential remuneration of such teaching staff, and upgrading of technikon qualifications. Members of high-level manpower are the custodians of public welfare in a free-enterprise society, and the foundations for this role are laid during tertiary education. Technikons should, as a matter of policy, be accorded autonomous status to afford an optimally conducive environment in this regard.

The rationalization and expansion of the existing tertiary educational infrastructure will depend very much on the detail of the new political dispensation. Changes will, however, not be required to be implemented with undue haste. The space available at universities will be sufficient for some time to come, but the technikons are already at a stage where they cannot satisfy the demand. Decisions on the establishment of technikon facilities for Blacks close to source will have to be made without delay.

The promotion, development, and guidance of engineering-student intake is probably the most overdue aspect, especially among Blacks, from whom by far the greater proportion of high-level manpower will have to be resourced in future. Definitive action in this regard will have to be taken without delay by instituted education and industry on its own behalf.

The financing of engineering education and training, in particular the remuneration of teaching staff, is of such magnitude and urgency that it has to be actioned separately. The market-related subvention of salaries for tertiary engineering and basic-science teachers in sufficient numbers alone will require considerable funds.

New employment opportunities should be created actively, at an accelerated rate, and according to a planned strategy. The number of jobs required and the annual increase therein are of such extraordinary proportions that the development of employment opportunities cannot be left to the normal market mechanisms. The sectors of the economy in which jobs can be developed should be identified, the necessary business infrastucture defined, and the funding procured on a suitable basis. Restrictive regulations should be removed, and local industries should be appropriately protected from undue external competition. The development of high-level manpower should be continually monitored to ensure that targets are met and that adjustments are made in good time.

Interests Identified

The interests involved in these actions are so diverse that no one organization or institution can attempt to take care of them all. Indeed, the following organizations can be identified as being able to contribute to one or more of the actions:

- Various existing State departments and corporations involved in engineering and industry
- Various State departments of education
- State department of technology
- Organized engineering education and research
- Organized industry
- Official vehicle for the development of employment opportunities
- Human Sciences Research Council
- Organized engineering.

The various existing departments involved in engineering works are major employers of engineering staff. The privatization of State services has the adjunct benefit of increasing the private sector's share in the provision of high-level manpower. Some of the infrastructural development will, however, always remain with the public sector, in which instance the departments involved will assume responsibility for the development of the associated high-level manpower. In fact, to the extent that State departments will dominate infrastructural development, they will remain responsible for certain branches of engineering, e.g. civil engineering, which are not in a position to exploit the economy to their own benefit.

The provision of high-level manpower is of such strategic importance and is subject to a backlog of such magnitude that the development of the human resources of the country should be actively pursued in terms of a unified strategy. The various departments responsible for education should be combined into one effective organization with definitive vision and direction, and should be responsible for education policy.

A department of technology is required to promote the interests and standards of technology in terms of a national strategy on engineering. The establishment of such a department will on its own immeasurably improve the stature of engineering. The department could, in addition to developing a national strategy on technology, be responsible for the rationalization and expansion of engineering education and training institutions, subsidized financing of tertiary engineering education, establishment of an official vehicle for the accelerated development of employment opportunities, and monitoring of the supply and demand for high-level manpower.

A formal cooperative organization should be established between the engineering departments of universities and technikons to liaise on common interests and to contribute to the formulation of overall strategies.

For industry to remain assured of an adequate supply of manpower, it has to become directly involved in the execution of some of the actions identified above. Industry can make a particular contribution to the assurance of useful research at universities and technikons by direct cooperative interaction in terms of the selection of research topics, the execution of research projects, and the provision of the necessary resources in the form of grants, bursaries, facilities, equipment, expertise, and guidance. An example of such action is offered by a number of industries, research organizations, and educational institutions with vested interests in the production and development of materials who have established a cooperative working group to pursue these objectives more effectively[28].

Civil engineering urgently needs the benefit of a similar working group. As the branch of technology mostly involved in the provision of infrastructural services, the cause of civil engineering will not be taken up as readily by commercially oriented organizations. The representatives of large employers of civil engineers such as the relevant State departments, Iscor, Eskom, the Federation of Civil Engineering Contractors, the mining houses, the Association of Consulting Engineers, and the tertiary educational institutions should initiate the establishment of such a working group under the auspices of the South African Engineering Association.

The active and accelerated creation of new employment opportunities can be achieved only by the establishment of an official vehicle similar to the Industrial Development Corporation and the Small Business Development Corporation. The mission of such an organization would be to specifically promote and assist with the establishment of industries for the primary purpose of creating new employment opportunities. It would obviously cooperate closely with the two related corporations referred to.

The Human Sciences Research Council will be required to continue monitoring the supply and demand for high-level manpower. This Council should indeed manage the national manpower budget and pre-emptively institute corrective action where targets are in danger of not being met.

Engineering interests have been organized during the past two years into a coherent body—The South African Engineering Association (SAVI), which represents most of the objectives of the learned engineering societies and engineering vocational groups. The specific purpose of the Association is to address a number of existing problems related to engineering, the requirements for engineering education being one of the main issues in this regard. The Association is pre-eminently suitable to coordinate the various actions identified and, more specifically, to play a leading role in increasing public awareness, developing a formal political lobby, and contributing to engineering-education policy and the rationalization and expansion of educational infrastructure, and to the promotion, development, and guidance of engineering-student intake. As evident from the following comments, SAVI has assumed an invaluable initiating role in the establishment of a programme of action.

Actions Taken

The Joint Committee on Engineering Education, Training and Recruitment of SAVI and SPE recently submitted a strategy[29] for the enhancement of the technological base of the country, in terms of which it is proposed to give effect to much of the above-described plan of action. The concept involves a coordinating, vetting, and implementing body between the Directorate of Technology of the Department of Trade and Industry, the Department of National Education, the Foundation for Research Development, the South African Engineering Association, and organized business and industry on the one hand, and various centres of specialization, institutes of technology, and existing tertiary engineering-education institutions on the other hand. This strategy forms the basis of the newly adopted Economic Advisory Council's programme for the development of the high-level technological manpower envisaged in the long-term economic plan for the country. The State President has indeed charged the Foundation of Research Development, in joint venture with SAVI and organized industry, with the urgent launching of the programme[28].

The joint venture will, in effect, fulfil the role of the abovementioned central broking forum with the primary mission of promoting employment opportunities and economic prosperity through the development of technology and technological manpower. The objectives of the forum will be to develop a technology policy, identify and promote appropriate fields of engineering education and research, synthesize research findings and effect technology transfers to industry, foster multi-disciplinary interchanges on national and international level between the various sectors of the economy and education and research institutions, improve the quality and professionalism of the engineering team, develop and rationalize tertiary engineering education, expand and improve the quality of the engineering-teaching corps, enhance the public appeal of engineering, and develop special programmes to sensibly increase the intake of engineering students from disadvantaged backgrounds. Qualifying staff of the various existing engineering faculties, schools, and research institutes will be utilized through centres of specialization and institutes of technology to achieve these objectives.

The mission of the proposed centres of specialization is to rationalize the pursuance of particular fields of specialization by obviating wasteful duplication and by focusing the efforts and financial resources of the educational, research, professional, governmental, and industrial interests concerned. Special tasks that have been identified in this regard are the identification of the objectives and interrelationship of university and technikon education and training; optimization of tertiary education facilities, accommodation, equipment, and staff; improvement of the interaction between members of the technological team; promotion of a significant increase in Black engineers and technologists; appropriate transfer of students between universities and technikons; development of a broader-based education for engineers; promotion of post-graduate coursework degrees in appropriate fields of engineering; promotion of essential engineering disciplines, where lacking; establishment of appropriate programmes towards professional registration; and review of engineering curricula.

The mission of the proposed institutes of technology is to coordinate, rationalize, and facilitate the activities of the universities, technikons, and centres of specialization on a regional basis. The object of these institutes will, in particular, be to maintain an intimate relationship between the universities and technikons in a particular region, to ensure their optimal unified functioning, to address the professional needs and interests of engineering students and, where required, to assist in the professional education and training of the students.

The centres of specialization and institutes of technology will achieve their objectives with the aid of university and technikon staff retained on the basis of one day per week. Such staff will be subject to peer evaluations, and are expected to significantly increase their remuneration in this way. It is estimated that R40 million per annum will be required to finance this action.

The proposed rationalized coordinating and management structure for tertiary engineering education is expected to win substantial commitment and financial support from various State departments, organized research, and the private sector. State departments will be invited, if not encouraged, to channel their technological research funds through the central coordinating body. The private sector will take up the challenge to the extent that the State departments and organized research commit their available funds to the cause. If this is achieved, a budget of R120 million could be raised annually for additional projects in particular fields of specialization.

The requirements for engineering education in South Africa are many-faceted and involve a very complex and extensive plan of action, as evident from the preceding sections of the paper. The proposed programme constitutes a strategy that is as comprehensive as could practically be determined. SAVI should be congratulated for the initiatives that it has taken in this regard so soon after its own constitution.

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SPOTLIGHT

on H.J. Joel Mine

by R.L.C. MAGGS*

The following members of the Orange Free State Branch and visitors paid a mini-visit to the H.J. Joel Gold Mine on 23rd January, 1991:

Members		*Visitors*
E.N.D. Westgate	Organiser	C. Knight-Hassel
R.L.C. Maggs	Hon. Secretary	J. Campos
S.V. Stander		E.W. Booysen
S.P. van Wyk		J. Steyn
D.S. Minnie		P.I. Masseratte
O.W. Fourie		C.J. Higgins
		S. Guven
		F. Scof
		N. Hastings
		R. Hays

On arrival at the Mine, the visitors were welcomed by the General Manager, Mr Chris Naude, who introduced the staff who would be involved in the visit.

The H.J. Joel Mine

The Mine has an excellent safety record despite problems with water and methane. The reportable injury rate moved from 31,90 in 1987 to 1,3 in 1990, which is the best in the industry. The safety record is clearly due to the commitment of all the personnel to safety, as well as to the high degree of motivation displayed by the employees.

The Mine is named after Mr H.J. Joel, who is the retired Chairman of the Johannesburg Consolidated Investment Co. Surface drilling started in 1981, and the first sod was turned in November 1985. Sinking started in February 1986.

The Mine is exploring and extracting the VS5, Beatrix Reef, which varies from 15 cm to 3 m in thickness. The reef dips at 16 degrees, but is mined on an apparent dip of 8 degrees to cater for trackless mining. The reef plane is eroded, and difficulty is experienced because of the erratic nature of the pay shoots. Water remains an issue, and fairly extensive de-watering is being done. The water is under pressure, with a high content of brine and dissolved gases, which in turn leads to a methane problem. An installed pump capacity of 60 Ml per day is available to cope with possible inflows.

* Freegold North Region, P.O. Box 3, Welkom 9460.

The existing main shaft has a capacity of 156 kt per month, and the Mine has a complement of 1800 people. The vertical spacing of the top levels (60 and 70) is 100 m, and the bottom level (90) is 200 m. The proposed new shaft system will have a vertical level spacing of 160 m. Ore passes are raise-bored at 67 degrees, with a diameter of 2,4 m, and each has an inspection leg for the blasting down of possible hang-ups. The ventilation capacity is 600 m^3/s, which is required for the operation of diesel machines. All the stores and materials are containerized, and the stores are drawn underground.

The two top levels are trackless, while the bottom level will be a rail-gathering haulage.

Water is handled in vertical settlers with horizontal dams.

Stoping is laid out on 40 m panels, which are on a minor dip of 8 degrees to cater for trackless machines. Efforts are being made to pre-develop gullies (3,1 by 3,0 m), and ledging is now being done using an Eimco–Secoma rig, which eliminates the need for platforms and the associated problems. Support is achieved with profile props, and with concrete packs in the gullies. Regional crush pillars are also used. Truckways are cut at 4,2 m by 3,7 m. The LHD units are planned to have a longest run of 150 m, while the trucks have an optimum of 600 m with a maximum of 1000 m. All the gullies and truckways are resin-bolted to stop bed separation.

The capital expenditure on the mine has been R611 million to date.

The Visit

The visiting group was taken underground and shown the tip area of 60 level, as well as the mechanized development on 90 level. The efficiency of the operation was impressive, 600 t per man being obtained monthly in the development ends. The telemetering system was seen.

The group went through the CIP plant, and saw the computer monitoring system. A tour of the single quarters and tavern was then made.

After an excellent braai at the 'lapa', Mr Westgate thanked Mr Chris Naude and Mr Noel Williams for their hospitality and the arrangements made for the visit. Special thanks were conveyed to the guides and to all the mine personnel who had made the visit so interesting and enjoyable.