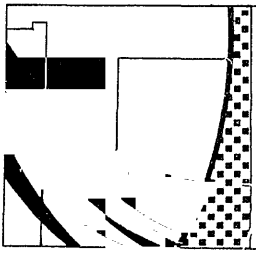


Engineering Education for a New Latin American Society

Mario Kamenetzky

Engineering encompasses all those professions characterized by using technological knowledge to produce goods and services. But engineers could also help to create new technological knowledge. A classification of these engineering professions is proposed based on the main type of natural and social structures or systems on which they act and on the qualities and characteristics of that action. Considering the plans for learning the different branches so defined, an equilibrium is being searched among:

- the scientific knowledge needed to produce new technologies
- the technological knowledge and the technical skills demanded by practical productive work, and
- the social and psychological knowledge needed to successfully deal with human beings as agents and subjects of scientific and production work.

The training for workers becoming technicians or engineers is separated from, and at the same time combined into, the training for full time students becoming masters and doctors in the engineering sciences. It is expected that, in all these degrees, engineers will help in overcoming misery, hunger and violence and in developing new Latin America societies where productivity and pleasure will not exclude each other.

Engineering in Latin America

Engineering uses available technological knowledge for designing, building and organizing productive units. It also applies technological knowledge to the production itself. But engineers can also participate in the creation of new technological knowledge through research and development.[1] This dual role is more explicit in the French language, where the identification of an engineer demands two words: "Ingenieur du Génie . . . chimique, civil, etc." Ingenieur comes from the old French, from "engine," which meant a war-machine and is equivalent to the

English "engineer" and the Spanish "ingeniero." It implies the practical productive work aspects of engineering. "Génie," on the other hand, comes from Latin, from "genius," and means "willingness or natural aptitude to create something original." It represents the innovative side of engineering. Concerning both aspects, the following problems have been observed in Latin American engineering:

a. Scientific research is not connected with local production of technologies.
b. The national technological and scientific systems are more strongly connected with the same systems in other countries than with their own societies and economies.
c. The engineering services for the creation of technological knowledge and for the production of goods and services are particularly weak in the fields of process and metal-mechanic industries and public services arising from recent innovations (satellite communications, nuclear power, etc.).
d. The know-how and, often, even the detailed engineering of the productive undertakings come from abroad.
e. Engineering education in Latin America leads engineers to use scientific and technological tools others have discovered, imagined, thought, felt, designed and experimented more than to discovering, imagining, thinking, feeling, designing and experimenting by themselves.

Latin American social and political schemes accepted that local engineering should be limited to the maintenance of imported productive installations and to the solution of some minor problems in housing and in public services. For a long time, Latin American engineering identified itself with the two great branches of the Napoleonic period: the "civil genius," applied to the development of buildings and public services for the population, and the "military genius" applied to the construction and services needed for war equipment.

The more specialized and diversified engineering branches have mostly developed in the Anglo-Saxon countries, as instruments for the industrial revolutions, and were often introduced in Latin America only as a supplementary aid to civil engineering. Even when those new branches reached the stage of independence from civil engineering, they continued to be strongly impregnated with the "genius" of the latter.

Specialization was conceived as adding heavy descriptions of the new technologies, the proceedings and the equipment used in the most advanced industrialized countries to the already encyclopaedic programs of civil engineering careers. Very few, if any, of the tools required for the local production of technology were provided. Such education, unable to promote creation, could not induce a progressive social change.

Sometimes, engineering education erred in the opposite direction, through a purely intellectual approach, preferring scientific discussions of

abstract statements to action. Then, engineers were overloaded with information on basic sciences to the detriment of practical engineering knowledge. At the same time, the possibilities of the basic science as instruments for the creation of technologies were not valued.

New Ways in Ordering Different Engineering Branches

Latin America has the opportunity and the possibility for a great leap forward. If, up to the present, she has been retarded in her engineering educational policy, she can now restructure her teaching, so as to place herself in the forefront. Little has been done in this effort in comparison to what remains to be done.

When restructuring engineering careers, Latin America could simultaneously reorganize and reorient education in all those other professions which share the objective of participating in the creation of know-how, on the one hand, and of applying the same to practical undertakings, on the other with traditional engineering disciplines. These professions could be ordered by the type of physical or social systems or structures on which they mainly exercise their action and by the type of fundamental transformation this action produces or controls (see Table 1).

TABLE 1. Engineering Careers

Level of action	Type of fundamental action	Engineering
Nucleus	Transformation of mass into energy and of one type of energy into another.	Nuclear
Atoms	Transmission and storage of information.	Electronic
Molecules	Chemical change.	Chemical
Materials	Shaping of materials and production and use of equipment.	Mechanical
Structures	Assembling of materials and combination of shapes for the construction of buildings, dams, highways, etc.	Structural
Economic systems	Organization of the production, distribution and consumption of goods and services.	Economic
Human body	Improvement of health conditions.	Biological
Natural systems	Production, distribution and use of natural resources.	Ecological
Habitat & habitation	Improvement of life through betterment of houses and cities.	Habitat
Social systems	Improvement of social conditions and regulation of human interactions.	Social
Educational systems	Production, transmission and storage of knowledge.	Educational

The proposal calls for the following considerations:

a. While engineering careers would always be characterized by the dual role mentioned earlier—the creation and use of technological knowledge—scientists would work with theories, models and taxonomies, thereby increasing the knowledge on Nature.
b. It is not the purpose to form either "jacks of all trades and masters of none" or "super-specialists." Engineers should have a full command of the specific tools required to perform an efficient job on each one of the described economic, social or natural systems, but they should avoid the blinders of over-specialization.
c. The type of work and the specific subject on which such work is to be performed within each engineering branch, would be a question of post-graduate option depending on each personality and on the restraints of the local social and economic environment.
d. The old art of curing would be gradually replaced by biological engineering which would encompass the techniques of all modern and traditional medical schools.[3]
e. In the same way, ecological engineering would replace and involve agronomy and the veterinary arts and sciences.
f. Economic engineering would substitute the present studies of economics and industrial engineering.
g. Engineering of the habitat would hold a wider concept than that of the inherited Greco-Roman architecture and would be a better expression of present architectural trends.
h. Social engineering would both substitute and enrich law.
i. An educational engineer would be able to specialize in teaching primary and secondary level students and in adult education. He would also devote himself to planning local educational structures or developing new means for the transmission and storage of knowledge.

Study Plans

Each of the study plans should contain four sections:

1. Education in basic sciences: chemistry, physics, mathematics, biology.

   In each case, emphasis should be placed on the most required instruments in each profession. In mathematics, for example, the biological engineer would go deeper into statistics and probabilities, based upon set algebra, rather than into differential and integral calculus. The engineers who would devote themselves to the design of physical structures, processes or products, need a good training in numerical and graphic calculus, but the notions of biology acquired in secondary school might be sufficient for them.

2. Education in engineering sciences.

   Structural theory and analysis and the nature and properties of materials for structural engineering; chemical thermodynamics, transport phenomena and chemical kinetics for chemical engineering; nuclear and atomic physics for nuclear engineering; economics and operational research for economic engineering; biophysics, biochemistry, anatomy and physiology for biological engineering. Subjects such as ecology, physics of the solids, electronics, sociology, etc., would be included in this section as required by the different branches.[4]

3. Technological education.

   Calculation of reinforced concrete and metal structures for structural engineering; equipment for the unit operations and chemical reactions in chemical engineering; electronic circuitry for electronic engineering; diagnosis and therapeutics in biological engineering; accounting and management techniques in economic engineering; etc.

4. Cultural integration.

   Theory and practice of mass communication; social anthropology and psychology; epistemology and history of science; social and economic analysis of national and regional development; the role of technology in social change; technology and human values and needs.

The first two sections would provide scientific information and introduce the students into the use of the scientific methodologies. The third one would put the future engineer in touch with the practical aspects of his profession. If it was stopped there, the graduate would have learned to design, calculate and handle equipment and materials or to analyze given structures or systems so as to be able to act upon them. But all engineering actions, transformations and operations are carried out by men and their end products are used by men. That is why it is necessary for engineers to know those men as individuals and as members of societies (social anthropology); how they feel and express their feelings (psychology); how they slowly learn to reason and to experiment (epistemology and history of science); and how they communicate among themselves.

Engineering schools cannot ignore the problems that boil and ferment in the streets. They must consider them in depth, avoiding anecdotes and dogmatic blinkers.

Organization of Engineering Teaching

Due to the dual role of the engineering discipline, one could observe the co-existence of two types of technical schools. One, which is classical, deals with full-time students and is supposedly more connected with the creation of technological knowledge. The other one, supposedly in close contact with the productive sector, is involved in teaching technical courses

during non-working hours for those who cannot afford to pay full-time engineering education.

Neither of the two comply well with their defined objectives.

As regards the first, it is because it often divorces from reality, escaping into abstraction. The second one arises out of a willingness to imitate the first, instead of looking for an original way. and only ends up to form "engineers with rebates" after having sacrificed most of the students' leisure time for many years.

The reorganization may call for a reform of the whole educational system. A good part of the education in basic sciences could be relegated to secondary schools thereby shortening the training period for undergraduates. This would evidently bring about social benefits, as the adolescents of the secondary cycle (13 to 17 years of age) do not subtract human resources from the productive sectors and the engineers could become productive at an earlier date. It has been demonstrated that, employing the appropriate method, the young could easily assimilate apparently complex physical and mathematical knowledge.

After the secondary school, full-time students could continue their studies towards obtaining a Master's degree in the sciences of nuclear, chemical, mechanical or any other engineering. They could then be able to choose between following post-graduate studies leading to a Doctorate or entering the productive system (see Figure 1).

A program for a Master's Degree in Chemical Engineering Sciences is given in the appendix as an example.[5]

A Master's degree in engineering sciences would average a total of 30 to 40 semester courses. Supposing:

- Four subjects are taught per semester, and
- Full-time dedication of students and professors during five months every semester, at the rate of 20 days per month and 8 hours per day; then

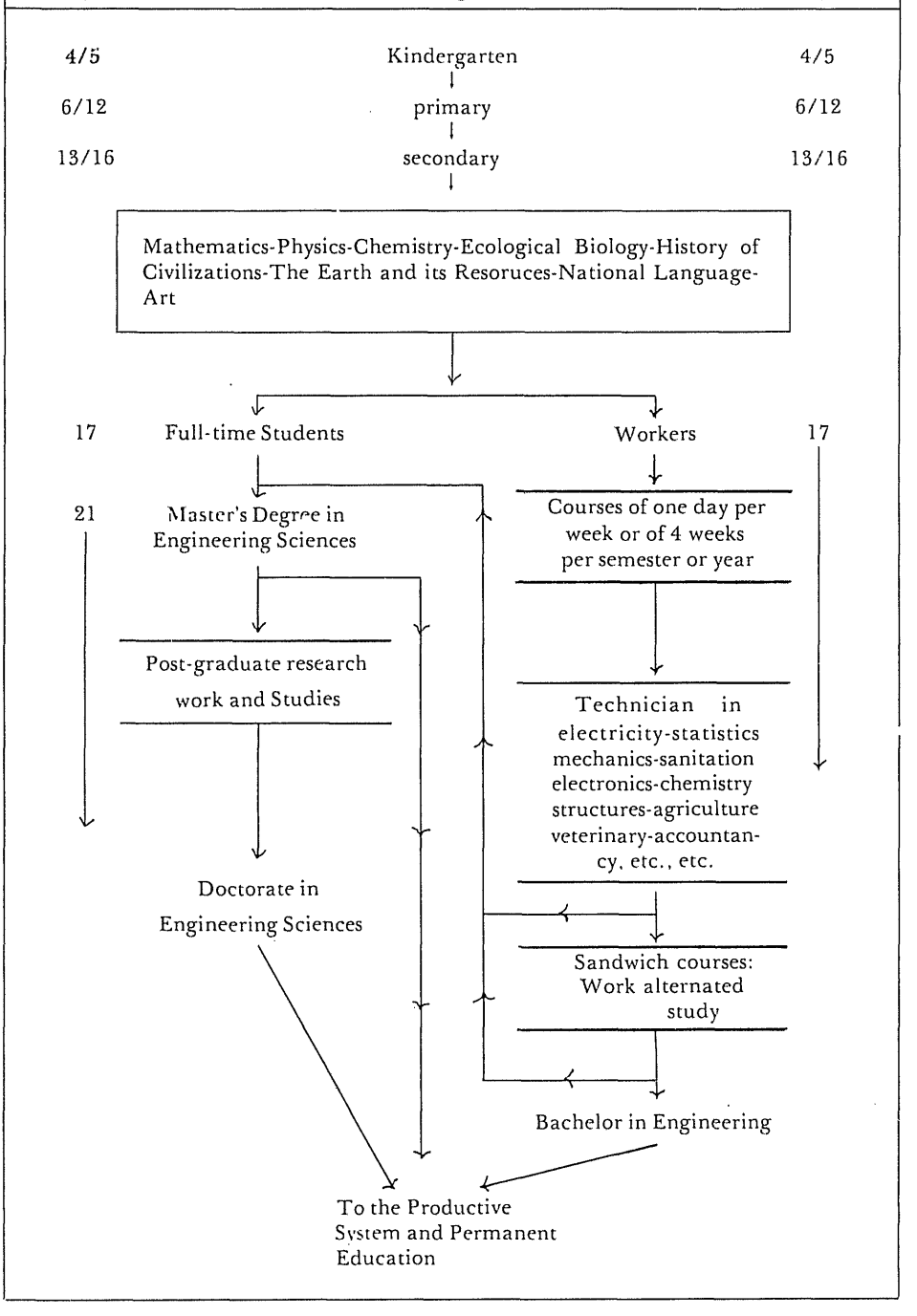
one would have:

- a variable duration of 8 to 10 semesters for the development of the whole program in each branch.
- an average availability of 200 hours per subject, which allows for sufficient time for classes, team work and personal study and work.
- sufficient leisure time so as to let both, students and professors, live a full life, satisfying their effective and instinctive impulses.

On the other hand, people who enter into production upon finishing their secondary studies, should be able to work and, at the same time, become technicians, as a first step, and, persisting in their efforts, engineering bachelors later on.

Workers should dispose of part of their productive time for education, without their earnings being affected. For this to occur, societies should be conscious of the benefits resulting from populations having a higher technical level.

Figure 1. Insertion of the Teaching of Engineering in the Educative System



Workers should attend semester courses of one full day per week or of four weeks of full time dedication. The result would be the preparation of technicians in electricity, agriculture, sanitation, etc., needed to form the intermediate technical teams demanded by the productive structures.

From that stage on, the bachelor's degree would be given after a series of courses alternated with working periods; for example, a semester of study and a semester of work during the four years. The study periods would be borne by the State or by the enterprises or by a joint effort. Those workers excelling in their studies should be psychologically encouraged and financially supported to enter into full-time academic training leading to a Master's degree.

The subjects to be included in the courses for technicians and bachelors of engineering would be similar to those scheduled for the corresponding Master's degrees in engineering sciences with an adjustment in their contents. The teaching techniques should also be different. They should be adapted to requirements, objectives and possibilities which differ from those of full-time students.

Technicians and bachelors would be mainly devoted to production or commercial tasks in already installed units. Masters and Doctors could also enter production lines, but, more often, they would dedicate their time to the design, construction, organization and administration of new production facilities, distribution systems and service trades; to the development of new technologies and to teaching.

Courses for full-time students and for workers should be organized under a common administration and share the same campus. There should not be academic universities for preparing elites on one side and universities for training labor (Universidades del Trabajo, as they are known in Latin America) on the other. Neither should there be an accepted distinction between traditional universities and technological universities (Universidades Tecnológicas, as they are often called in Latin America). Science, technology, arts and crafts, should all concur in providing satisfaction to human needs.

The only requirement for entering the courses for workers should be their desire to supplement manual ability and technical skill with the theoretical knowledge of the subjects in which they are working. Anyone willing to do so should have a chance. This might require a national organization for the permanent education of workers able to face simultaneously the requirements of a heterogeneous demand and the limitations in available educational resources and the amount of time for educational purposes allowed to the applicants. Computer work for programming each individual's calendar on the basis of the possibilities offered, at each moment, by the regionalized network of courses may soon appear to be indispensable.

For full-time Master's courses, a selection of the students seems convenient. Only those with a great potential in dealing with abstract knowledge and in imagining solutions for problems should be admitted. Examinations are neither the only nor the best method for such a selection.

Long conversations with a well-trained psychologist, complemented by well-selected tests, could perform much better.

In both types of courses, the teaching should be carried out by well remunerated, full-time professors, capable of performing research work or of participating in practical studies and design work. Part-time magisterial teaching would be tenaciously defended in Latin America by those who practice teaching as a sideline activity adding more to their prestige than to their income. Serious obstacles would also be encountered when subjects in the different study programs have to be abolished. Many subjects in the various engineering careers are taught simply because they are traditional, or because professors do not feel capable to face a different kind of teaching.

The proposed educational schemes should prefer a continuous evaluation of the learning process to periodic memoriter examinations. The former could only be accomplished by an active and permanent dialogue between professors and students, using different channels of communications.[6] Opposition to such a reorganization could well also come from the students themselves, accustomed as they are to repeating stereotyped exercises and problems.

Final Considerations

The model which is proposed is not utopic, but one should be fully aware of the difficulties its application could encounter. Unfortunately, almost everywhere, universities have been structured around competition for prestige and power. The search for a balance among the man who produces (homo-faber), the man who thinks (homo-sapiens) and the man who enjoys (homo-ludens) is reaching the universities, although only very slowly.

To these sort of obstacles, which would be universally met when trying to apply the model, one may add, for Latin American countries, the fact that large sectors within their societies are still imbued with a pre-technological mentality in the sense of a "methodical and conscious disaffection towards the world of business and industry and its order founded upon calculation and profits" (Marcuse, 1968).

For these reasons, the proposal must be considered as a long-term objective, to be gradually reached through promoting change, theorizing about it and continually recreating the educational technology. University life (and also that of secondary schools) should be reorganized in such a way so as to constitute a social model, combining the principle of reality (performance, efficiency, productivity) with that of pleasure, in adequate proportions. Students would then feel that institutions external to them – such as money, laws, work, etc. – continue to exist and keep being alien to man's nature, because of their "demanding the expenditure of energy in favor of third parties and not for the satisfaction of the needs and desires of the individual" (Brisset, 1967). But, at the same time, students would grasp that this alienation could be restrained and restricted for it to affect the individual only provisionally and partially.

Education should identify itself with life. Learning must be accomplished by employing hands (doing); brains (imagining and reasoning); hearts (feeling) and the whole person (fulfilling pleasure). Students would, then, be induced to promote a social change in the same direction when working in their respective social and economic national systems. Engineers might particularly be influenced to produce and use technologies primarily aimed at satisfying genuine human needs, instead of fulfilling publicity induced desires (Mellman, 1973 and Kamenetzky, 1976). Engineers should also learn that technologies must always be adapted to the social, economic, anthropological, psychological and environmental conditions of each particular investment project.

Such technologies should produce goods and services with the least possible aggression to Nature and human beings. They should also favor an equitable distribution of income by promoting the participation of producers and consumers in designing the objectives of the productive undertakings and in controlling the evolution of the undertakings in their path towards achieving those objectives. Finally, technologies should aim to maximize free time for it to be applied to pleasurable activities. Since Latin America recently joined the industrial race, she is still in time for redefining and re-thinking her technological policy instruments so as not to repeat technological mistakes that have damaged the physical environment of the industrialized countries and allowed ugliness, violence and alienation to build within their societies.

Engineers should focus on creating not only new and better hardware (products, machines and facilities) that will promote progressive changes in economic patterns and life styles, but also improved software (institutional, legal and social practices) that will keep pace with those changes in manners, opinions and circumstances.

Engineers should use scientific and technological knowledge in a way that will be perceptible to the senses as well as to reason and understanding—a way that should enable them to become emotionally and consciously aware of the fact that for all human beings the principal buisness of life is to enjoy it.

APPENDIX

Proposed Outline for a Master's Degree Program in Chemical Engineering Sciences

1. Basic Sciences

1.1 *Chemistry (4)*

Atomic structure: the spectrums.
Types of chemical bonds and the formation of molecules.
Theory of acids and bases.
Organic Chemistry: structural and functional groups.
Inorganic Chemistry: elements and their reactions.

The solid state: crystals and metals.
Liquids and changes of state.
Radiochemistry and the nuclear properties of matter: isotopes and radioactivity.

1.2. *Physics (3)*
Mechanics.
Electromagnetic, acoustic and mechanical vibrations.
Geometrical optics.
Physical laws and relativity.
Quantum theory.

1.3 *Mathematics (5)*
How to treat and interpret engineering data.
Algebraic equations.
Differentiation and integration.
Statistics and probability—Algebra set.
Ordinary and partial differential equations.
Vectorial and matrices algebra.
Numerical and analogical calculations: computers and programs.

2. Chemical Engineering Sciences

2.1 *General Thermodynamics (2)*
General postulates: states of equilibrium-internal energy-enthropy-statistical significance of enthropy.
Relation between intensive and extensive parameters: Ideal and real gases.
Quasi static processes—Reversible and irreversible processes.
Thermodynamic cycles and engines: refrigerators and heat pumps.
Thermodynamic potentials: free energy-Enthalpy-Free enthalpy-Legendre's transformations.
Maxwell's relations: compression and expansion.
Stability and phase transitions-Le Chatelier's principle-Phase diagrams-Latent heat.
Properties at zero temperature-Nernst's principle-Thomsen Berthelot's principle.
Properties of simple solids and liquids.
Thermoelectric and thermomagnetic effects.
Thermodynamics of small systems: bubbles and drops.

2.2 *Chemical Thermodynamics (2)*
Chemical equilibrium-Degree of reaction-Heat of reaction-Simultaneous reactions.
Stability-Le Chatelier's principle and Gibbs rule for chemical systems.

Theory of fluctuatins in thermodynamic values-Functions of distribution-Average values-Moments.
Affinities and fluxes-Onsager's relations.
Fugacity and activity.
Calculations of affinities: practical application in chemical reactions.

2.3 *Chemical Reaction Kinetics (2)*
Chemical reaction as a complex phenomenon where extensive parameters are transported, transferred and transformed.
Rate equations and interpretation of kinetic data.
Homogeneous and heterogeneous reactions.
Catalysis.
Stability and optimal design of reactors.

2.4 *Physical Kinetics (2)*
Heat, mass and momentum transfer.
Transport Phenomena in dispersed and porous media-Fragmentation and agglomeration of solid grains-Kinetics of granular transformations-Dispersion and coalescence of drops and bubbles.
Applications of the dimensional analysis, the numerical and analogical calculations, the thermodynamics of irreversible processes and the kinetic theory of gases to transport phenomena problems.
How to calculate and estimate engineering properties: conductivities; diffusivities, specific and latent heats; viscosities; densities, etc.

3. Applied Technologies

3.1 *Materials and Equipment for the Chemical Industry (2)*
Design and calculations, applying the concepts of physical and chemical kinetics, of equipment for:
— heat transmission and generation.
— movement and storage of solids, liquids and gases.
— transformation of size or state of aggregation.
— preparation of mixtures and separation of phases.
— preparation of solutions and separation of components.
— chemical reactions.
Selection of materials-Corrosion.

3.2 *Analysis and Control of Processes (2)*
Measuring extensive and intensive parameters: classic and instrumental methods.
System analysis.
Regulation of systems.

3.3 *Drawing (2)*
Mechanisms and equipment.
Lay-outs and flow sheets.
Maquettes.

3.4 *Process Engineering Economy (2)*
Financial mathematics.
Notions on business finances: capital formation; markets; balance sheets and statements of accounts, programming and budgeting.
Estimation of investment costs and of operational costs during pre-investment work.
Cost optimization-Linear and dynamic programming.
Selection of alternate technologies as a function of market size; availability and cost of capital, labor and raw materials; anthroposocial characteristics of population involved and ecology of the region.
Evaluation of investment projects: profitability and social cost-benefit analysis.
Management of projects, of industrial plants and of enterprises.
Research and Development management: selection and control of R & D projects.

4. Cultural Integration

4.1 *Economies and Societies in Latin America (1)*
The early times and the independence from European colonialism.
Sectorial economic evolution: agrarian, industrial and financial.
Foreign economic influence and nationalist reactions.
Problems of growth and development.
Social structures: demographic problems, social unrest and ideologies.

4.2 *Epistemology and History of Science (1)*
Infrastructures and superstructures-Theory and practice-Science and Politics.
Levels of analysis of reality.
Science, technology, art and society.
Models, theories and taxonomies.
How scientific theories are constituted.
Scientific knowledge as a particular case of general knowledge: other approaches; alchemy as an example.
Generation, transmission and use of knowledge.

4.3 *Psychology (1)*
Human requirements and socio-economic planning-Needs and desires.

The economics of the libido at the social and at the individual levels.
Performance, efficiency, productivity, consumption, publicity and pleasure. Alienation and satisfaction. The role of technology.
Sexological social problems: reproductive, recreational and relational aspects of sex. Prejudices and taboos. Reverse relation between body pleasure and violence.
Sexual information and education. The couple and the family. Birth control.
Psychology of creativeness and of work.
Some Latin American psychological problems: "machismo" (exaggerated assertion of masculinity and submission of the female)-institutionalism-hope centered upon "those from abroad"-hopelessness regarding "ourselves"-divorce of education from the reality of business world-self-repression of originality (fear of burning one's fingers).

4.4 *Theory and Practice of Social Communication (1)*
Place of man in the cosmos: phylogenetic culmination and cultural condition.
The differential characteristics of human beings: biped-station; binocular vision and language.
Cultural and biological systems: their adaptation to the environment.
Relationship between the sciences of language and the other sciences.
Symbols and signs in language.
Elements in the communication process: emitting and receiving sets; channels and messages.
Psychosocial aspects in communication: autonomy, participation, indispensability, interactions, the leader, the myths.
Popularization of knowledge and conformation of public opinion.

NOTE: The figures in parentheses indicate the number of semesters of teaching that the author considers appropriate for the development of each subject.

FOOTNOTES

1. It is useful to differentiate the concepts of scientific and technological creation from those of research and development. Creation means an increment or a modification in the scientific and technological knowledge. Scientific and technological creations can accumulate in an economic system and can be transferred from one system to another like capital goods. On the contrary, research and development constitute services rendered for the creation of knowledge and, as such, they are destroyed at the very moment they are produced.

2. For instance, 5,000 full-time research workers were recorded in Argentina in 1968 and 46,000 were estimated to be necessary for 1980. Resources assigned to the scientific and technical system for the same country in 1968 reached 48 million dollars and 2,400 million dollars would be needed for 1990 (Mallmann, 1971). The number of university students in Argentina is estimated to double between 1970 and 1980 (Taquini, 1970).
3. The apparent confirmation of the points of insertion of the millenary Chinese acupuncture, by means of photographic studies of the human body in high frequency fields, is a good example of what can be obtained when reviewing old wisdom with new, powerful experimental instruments (Ostrander & Schroeder, 1970). It is worthwhile to remember Sir Francis Bacon's words, "Some dispositions evince an unbounded admiration of antiquity, others eagerly embrace novelty, and but few can preserve the just medium, so as neither to tear up what the ancients have correctly laid down, nor to despise the just innovations of the moderns" (Bacon, 1620).
4. The enumeration of subjects does not pretend to be exhaustive. A few ones have been selected, in each branch, as examples. Study plans must be adapted to the conditions of each country and designed by a team of broad-minded engineers of the branch concerned assisted by experts in the subjects to be included.
5. The programs for psychology and for theory and practice of mass communication, proposed in the appendix, stem in part from an experience in interdisciplinary postgraduate education, in which the author participated as a professor for two years (1971/72). It was held in Buenos Aires under the title "Course on Theory and Technique for the Promotion of Change," in the School of Psychohygiene and Social Communication founded and directed by Eva Giberti.
6. In 1964-65, while the author had the chair of Industrial Technology in the School of Chemical Engineering in Santa Fe (Argentina), an experimental scheme was put into practice replacing final examinations for a joint evaluation by professors and students of the progress of team work.

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