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TRIDIMENSIONAL APPROACH TO TEACHING FOR INDUSTRY [1]

by

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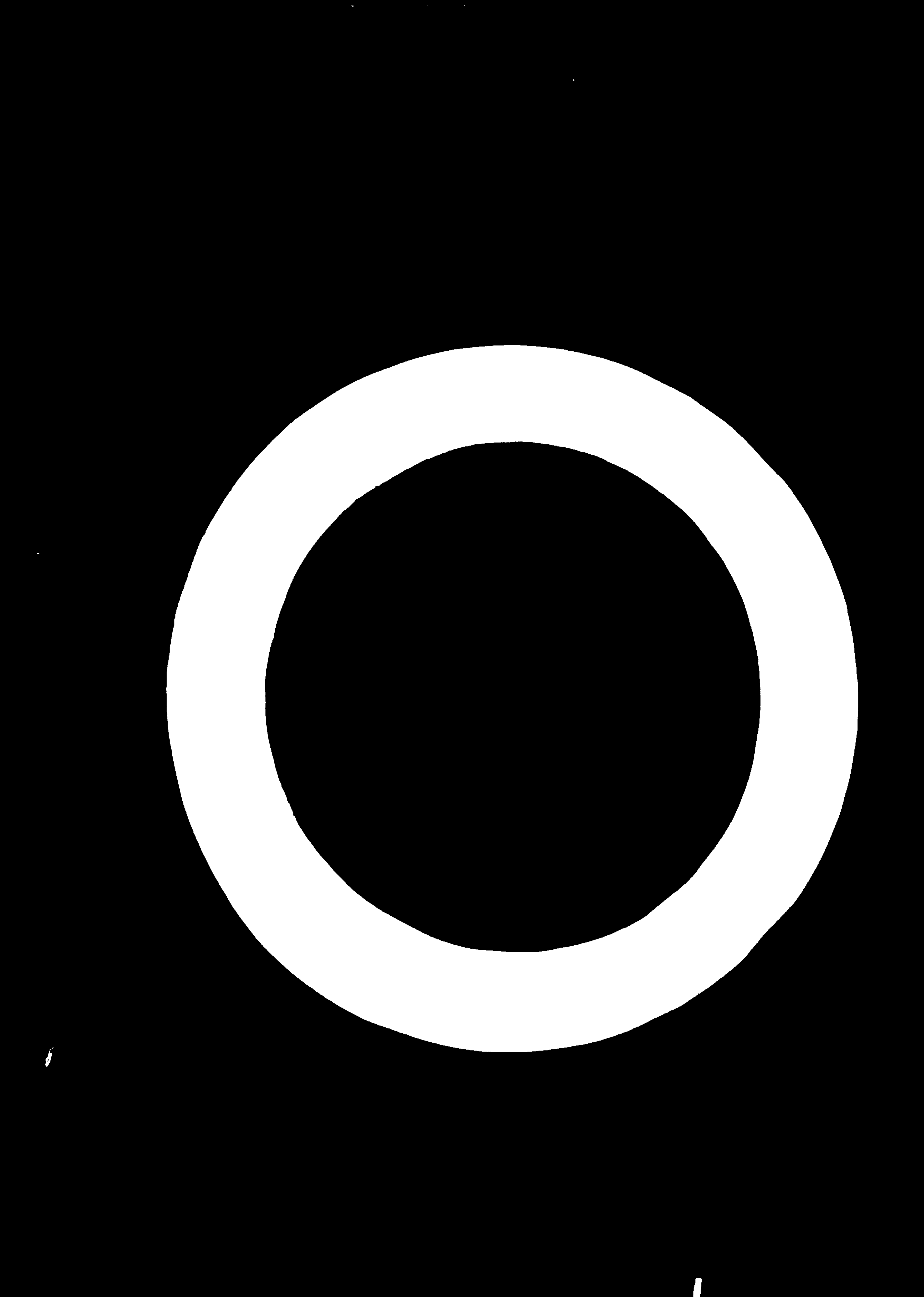

TRIDIMENSIONAL APPROACH TO TEACHING FOR INDUSTRY

1. Nature of technical work in industry

In spite of the bewildering variety of industries existing today, all the techniques on which they are built up are composed by combinations of individual operations performed on materials, energy, and data. Performing an "individual operation" constitutes a step in "processing". When processing materials, one always resorts to energy, and acts on the basis of data collected and interpreted before, during, and after processing. In turn, energy can be processed only when associated to material sites which participate actively or passively in processing, accomplished again on the basis of data characterising the whole thing; finally, data is processed by operating on energy or materials, the data being processed corresponding biunivocally to the physical characteristics of the energy or the materials operated upon. So, materials, energy and data appear in all processing. The distinction between "processing" (man-provoked changes), and natural phenomena, is the deliberate role that "data" is given in the first. Man measures, estimates, or calculates, poorly or accurately, correctly or wrongly, the variables intervening the processing he wants to undertake, and acts accordingly. This is true of the cave-man who needs a stick for self-defense and cuts a branch from a tree after pondering its lenght and weight, as is for the optician who grinds a precision lens.

Being able to perform one single step in processing, or several related steps of basically the same kind constitutes a "skill".

Although at times the final objectives in processing can be achieved through the application of a single skill, this is not usually the case. Combining individual operations of different nature (thus requiring different skills), constitutes a "technique". For instance, a screw can be, if so desired, produced utilising one single skill, turning, but in making a gear one should resort to a number of other individual operation, such as milling, heat treating, etc.; and the whole is referred to as a "technique". One says that "technical knowledge" is required to ensure that the appropriate operations, tolerances, sequences, materials, etc. are performed, adhered to, followed, or utilised when combining individual operations in processing. Technical knowledge therefore requires an awareness of the tools, of the operations to be performed, etc. although it is not akin to a skill.

This gives a clue to the nature of the work of the technician; he deals with what pertains to putting together single operations related between them by the fact that they contribute to processing of materials, of energy, or of data, as the case might be. So, for instance, if processing is set to produce gear-boxes, the technician will set and oversee the various machining steps required, which entails control of materials utilised, tolerances, assembly; if processing will produce paper from pulp, the technician deals with the successive operations called for, such as mixing-in additives and water, sheet forming, drying, calendering, etc. and their matching, as well as looking after the performance of equipment, control of the process, etc.; if processing energy, the technician will deal with the transformations occurring, their characteristics, stability, etc. and with the equipment utilised. In all cases, his dealing with the concomitant or successive operations, calls for his looking after the characteristics of the products or of the transformations, and using the information obtained to adjust the individual operations; by the same token, he will look after the performance of the equipment and its functioning, the rates of production, the efficiency, etc. all this constituting elements in the feedback cycles fundamental in all processing.

All that preceeds indicates that the work of the technician, as defined here ("what pertains to combination of individual operations in processing of materials, energy or data") can be extremely varied : the number of combinations of individual or successive operations (feedback included) that may occur in processing is enormous.

But he does not need to be skilled in all the operations he might deal with; his work calls for "knowledge" on the individual operations, their possibilities and limitations, and those of the materials; the standards applicable, etc. Equally important is the aptitude to combine operations to achieve the results sought in the simplest way, to control and modify them for more efficiency, for fuller and better utilisation of the equipment, to ensure the performance of the latter through adjustment and eventually repair work, etc. All of this can be denominated "technical knowledge and aptitude".

We have this far characterised the two first "orders" of activities as to the aptitudes needed in the individual:

- The "first order" corresponds to <u>skills</u>, the ability to perform, assisted or not, one single step in processing, or several related steps of basically the same kind.

- The "second order" corresponds to <u>technical competence</u>, the aptitude to deal with all that pertains to combining single operations into a well defined stage in processing.

Up to this point, we have dealt with individual (single) operations, and with their combination for production, more in general for processing. The somewhat detailed precisions included above on technical activities, perhaps the most confusing, clear the way to define the rest, in which elements other than technical start to play an increasing part :

- The "third order" of activities corresponds to the aptitude to set a work a predefined process so that the constituting operations meet the double constraint of technical correctness and feasibility, plus optimal scheduling. This includes choice of materials and operations for optimal performance and economy, critical path analysis, scheduling of operations and maintenance cycles, inventory control, manning and the like. While the "second order" of activities are those of an executant, the "third order" belongs to an organizer of production at plant level : these activities thus require discernment on "technico-organisational" matters *.

- The "fourth order" generalizes the preceeding concepts and moves into areas broader than operation or production within predefined processing and objectives. It consists in choosing among different processing possibilities, raw materials, volume of production, type products to be made, specifications, etc., attempting at optimal overall operations. Awareness of the skills is less and less necessary. All of this broadly corresponds to the usual concept of "engineering". The engineer would then be characterized primarily for his judgement on "technico-economic" matters.

These four "orders" of activities embrace production operations in somewhat static conditions as to technological development. They would normally ensure sound operations within the prevailing conditions and knowledge. They do not guard against change, obsolescence, competition. Then :

- A "fifth order" comes into play when innovations are introduced with regards either to materials, products, equipment or processing. All this requires "technico-innovatory" capabilities, and embrace design, conception of new products and equipment, use of non-conventional materials (for instance "local" materials), improvement of existing equipment, devising new processes; more in general they consist in shifting the boundaries of the known technology ("known" to the individual and to the technical or industrial community in which he works) If we resort to the usual wording, we would be referring to a higher type of "engineering" work, frequently supported by R&D activities.

* Denominations such as "high level technician", "operational engineer", "ingenieur-technician", "industrial engineer", etc. correspond roughly to certain modalities of work of the nature described under the third and fourth "orders" of activities.

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We shall not deal with other functions not directly influencing the technical aspects of production or of industry, but which have a bearing on overall operations (including financial aspects, sales, etc.) and particularly on their development along the time. But it is unavoidable to think of a "higher order" of activities, that concerning "systems". So far, we have dealt with what occurs in producing goods, services, or information, within the boundaries of one or several related processes. However, todays' realities require more and more to plan, to conceive, to realize projects embracing a number of major production or processing activities interrelated so as to require coherent and concomitant definition, design, setting up, and operation.

Then, processes are combined very much like individual operations were in the preceeding discussion. "Processes" is used here in the broadest possible meaning, and include services, etc. as will be seen below. Three type systems can be identified:

- Systems where the technical or scientific considerations prevail. This is the case of a meteorological data collecting network, of a defense system, etc. Cost considerations are done by comparison with similar or substitutive solutions, rather than with respect to product value.

- Systems of a technico-economic nature, such as a nationwide or regional communications system, a complex data processing installation, a river basin development project including energy generation, irrigation, flood control, etc., a petrochemical plant and its utilities, storage, transport facilities. These systems are the most closely related to industry.

- Systems for which the defining elements are of a technico-economic and social nature, such as industrial complexes, a satellite urbanization, regional (physical) planning (aménagement de territoire), etc. A number of elements of relatively new conception enter the picture, among them pollution control, utilisation of industrial wastes, etc. alongside with more traditional ones such as transportation, utilities, etc.

Because of the unique nature of each system, there is no point in speaking of work within a pre-defined step-up, that is, the realm of the skilled workers and technicians. Each case is a case of macrodesign, and this is the main difference with the common technical activities. However, some aspects within the second type of system listed above are amenable to a more or less general treatment, and some of the tools of ordinary design, such as PERT, operations research, etc. apply. At any rate, the aptitudes needed to deal with systems are to be found in a team, rather than in an individual. The problem of management

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related to technological or scientific achievement acquire a new dimension: the traditional pattern of work, i.e. in-line organisational units where the heads are assisted by his subordinates, becomes more and more inadequate.

The capacity to tackle matters with an interdisciplinary outlook, not only within technology, but also embracing the natural and social sciences seem indispensable on the "conception" side, along with the ability and insight to plan for the future. Naturally, every "system" is eventually fragmented into components that are handled as described when talking about the five "orders" of activities.

2. Grouping of operations

The individual operations that are at the basis of all processing can be grouped using as criteria the nature of the modifications performed on materials, energy, and data.

Each group would comprise similar operations, "similar" in the sense that they are based on the same kind of physical principle. These we will call "type operations". For instance, turning, milling, filing, grinding, etc. are all based on removing materials by applying shear solicitations on the pieces being worked on. These are grouped as a type operation that could be called "removal of material".

One possible classification of type operations is given in the attachment and consists in 25 of them. They constitute a continuum, going from the easiest to conceive (changing the position of materials), to the most subtle, the operations with information.

The fragmentation and classification as given is certainly amenable to further scrutiny and elaboration. On purpose, some of the type operations are very broad (for instance mass transfer, or processing of internal energy, or transportation), and could be advantageously broken down. However, this is not necessary for the purpose of this paper, and besides, in some cases, the names have a clear meaning as to what operations they embrace. For instance, "mass transfer" can be subdivided in a good number of the so-called unit operations in chemical engineering. The same basic phenomena govern all of them, however, and therefore it is legitimate to use a common denomination.

Historically, certain type operations were associated with certain materials. For instance, operations 7, 8, 9, 10 used to be especially applicable to metals and particularly steel, bronze, cast iron, etc.; and since these materials were utilised mainly to make mechanical apparatus, those operations (plus some others) are usually regarded as constituting the field of mechanical engineering.

In fact, the operations 7 to 10 apply nowadays to a large variety of materials and for many different purposes, and so it is no longer rational to think of them as belonging exclusively to the classical mechanical engineering. The same is true of the operations with energy. Electrical energy was of particular relevance to practical applications, and this gave birth to electrical engineering while other forms of energy were given scant attention both in teaching and in professional life.

But nowadays, drawing of usable energy from chemical sources and from nuclear reactions; the combustion pile; the direct conversion of radiation into electron flow, etc. entice to assume a more rational approach. Not only that, but obtention of mechanical energy from, say, combustion, was loosely tacked to mechanical engineering mainly because, on the one hand, the devices (engines, boilers, etc.) were made of steel, cast iron,

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etc. that is typical mechanical engineering materials; and on the other hand, because the energy thus derived was mainly used to drive machine tools and mechanical equipment. Then the advent of Chemical engineering approach to processing introduced vaporizing devices of all kinds, furnaces, flue gas heaters, re-boilers, CO-boilers, gas engines, etc., in every respect similar to the traditional steam boilers and combustion engines but constituting integral parts of processing units. So, nowadays, one thinks of boilers, combustion engines, condensers, etc. less and less as mechanical equipment and more and more as devices for processing of energy. The well known divorce between the "production" and the "thermo" men goes hand in hand with the preceeding remarks.

All this entices to speak about "energy transformations" thus setting the basis for a unified approach of energy processing. More in general, the preceeding considerations would indicate a need to reorganise and even re-name the divisions of technology as they stand now. More logical groupings of type operations both in teaching and in professional practice would lighten curricula and allow for a more rational approach to technical problems and to the use of materials and equipment.

For our present purposes, it suffices to draw attention on the continuum of individual operations, and try to see what patterns emerge from it that can be of use for a rational approach to teaching. This matter will be examined more in detail after we discuss in the next chapter a most important aspect in the performance of operations. At any rate, the few general remarks that have been included in the diagram are indicative of certain patterns.

3. Degree of technical sophistication in performing operations

It is worth noting that several grades of "technical sophistication" in performing the individual operations are possible:

- manual (including artisanal work),
- assisted (powered tools or equipment;application of energy),
- automatized (programmed steps in machines, etc.)
- controlled automatically (incorporating a feed-back control cycle).

The attached scheme includes the range of technical sophistication usually encountered in the performance of the operations listed along the abscisse.

It is interesting to note that:

- There is a gradual shifting away from manual operations as one progresses along the type operations involving materials, energy and data. In fact, from roughly one third of the scale on, is impossible to conceive manual operations (although setting the conditions -physical variables, timing, etc.-, for the transformations to take place can be done manually.

- Automatization is seldom encountered (in relative terms), in the simpler operations. In fact, the economics of automatization of operations where odd shapes, discrete (as opposed to continuous) displacements, trajectories other than those easy to generate by links, pivots and cams, etc. weighs heavily against simple operations such as assembly, transportation, fastening, etc. unless numerous repetition reduces the unit costs. "Automatic" is used throughout as self-acting, predetermined as to actions and their sequence, and occurring by virtue of equipment and set conditions not requiring continuous manipulation or re-setting.

- The need for physical skills diminishes when going from the first to the last type operations, while the requirement as to intellectual capability and rational comprehension of the phenomena involved increases.

One can speak of "skilled worker" with pertinence only when the degree of automatization is not substantial; if it is, is more appropriate to refer to "operative". In the latter cases, the worker does not manipulate the thing to be transformed, but sets and oversees the equipment that effects the transformations

A "skill" is really the ability of conducting hand or powered tools or devices, so as to perform the desired operation. If the movements and action of the tools or devices is programmed and occurs automatically then one can not speak of "skills" although one can refer to "specialisations".

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- At the technician level, one individual usually deals or can deal with 2,3 perhaps 4 of the type operations. Since there is a gradual change among neighboring groups, usually the work of a technician embraces a more or less well defined area of the scheme. More in general, one can associate certain fields of engineering (as understood today) to certain areas of the diagram. For instance, Civil engineering resorts for the most to operations within the first 6; Mechanical engineering from 3 to 10; Chemical engineering 13 to 15, etc.

- Another remark worth making is that leaving aside the pure skills, the other four "orders" of activities bring in elements of combination of operations, scheduling, optimization, innovation, that is, the elements time and change. The bi-dimensional representation flattens the picture, while the third dimension brings in the dynamic side of industry, the way technical knowledge (the flat picture) is put to work. This should also be paramount in designing training curricula; especially for "orders" of activity two to four, those more closely related to the conditions in which work takes place in industry.

- It is clear that the choice as to modes of operation is based more and more on technical considerations as one moves to the right; manual action, more in general "labor", becomes less a defining element when dealing with "matter" (transfer phenomena) and even less when it comes to energy and data.

So, when selecting processes, designing, and constructing equipment, the solutions for the operations referred to are dictated by technical considerations conditioned, naturally, by the omnipresent economic factors. But it can be said that technically speaking the design and operation of a chemical plant (involving mass transfers, energy transfers, chemical reactions), will be done in essentially the same way regardless of the stage of development of the country. But operations such as packaging, or transportation, or use of the final products, which may involve operations included in the first half of the list, could differ enormously depending on the local conditions.

In fact, when "manual" execution of operations is feasible, the diversity, relative value, and implications of the possible solutions (and combinations of partial steps) are far more difficult to extricate, and depend a lot more on the local conditions. The technical and economic considerations are no longer straight-forward; investment, employment, product design, management, even social aspects become essential.

These considerations are indeed important when comes to teaching for the "orders of activity" described above, under 1. The case of training for design will be dealt within more detail later on, under 4.

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- At the end of the scale one could speak of a "mental" mode of performance of operations on data (or information, more in general). This would complete the spectrum, with automatized operations at the Centre. Needless to say, manual operations require accompanying mental processes, that "control" the operations, as discussed under 1. above.

By the same token, mental processing is accompanied by some physical activity such as speaking, writing or any other means of recording or conveying information.

- An interesting remark stemming from what preceeds, is that the graphic could be better presented as a cylinder, as it is done at the bottom of the page, joining the "manual" and "mental" ends. So, the mode of operation diametrically oposed to those two, is the farthest removed from the way man would act relying on his own means.

- Finally, the scheme could be completed so as to include an indication on what "orders of activity" predominate for each type operation represented in the absisas. However, this would call for a three-dimensional diagram, with individual operations occupying closed areas perpendicular to the abscissa. The succesive areas would define a sort of warped cylinder, indeed difficult to present on a plane.

4. Teaching

Following all that preceeds, a logical approach to teaching would include three dimensions:

1. type operations
2. degree of technical sophistication appropriate to various production or operational set-ups
3. "Orders" of activity (skills, techniques: technico-organisational technico-economic, and technico-innovative functions)

The first heeds to the universality of technology: the second, to the extent up to which is possible and/or justifiable, and/or necessary to resort to equipment to perform the operations, as a function of technical plus local conditions (including volume of production, capital availability, etc.); the third to the local elements that condition the internal arrangements for a given, more or less well defined type of production.

The approach that prevails almost everywhere contemplates almost exclusively the first dimension. The equipment relative to the operations dealt, is usually mentioned or described alongside with the operations, but without referring systematically to the total range of possibilities. What is more, seldom if ever the economic (and other aspects) of the modes of performance of each type operation is discussed.

And the diversity of modes of performance is far greater for the operations within the first half of our classification, that is, those corresponding roughly to mechanical operations. The picture is further complicated in this area by the diversity of materials available nowadays, and the countles goods that a modern economy can produce.

Needless to say, the features incorporated in every mechanical design imply the modes of operation to be resorted to in the production stage. And reciprocally, the actual possibilities as to modes of operation, and their economics, limitations, shortcomings, etc., influence design. This constitutes a clear difference with design for operations at the upper end of the scale: a detergent plant can not technically differ except in details or size, regardless of the status of development of the country where it is to be built; a high voltage alternator and more in general a power generating plant, can be said to follow international standards as to design, construction, operation, and control.

But a cooking range, or a washing machine, wooden boxes, furniture, bycicles, or valves, can be designed and/or manufactured in widely different ways.

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It so happens that mechanical production, particularly of light goods, occupies a key place in industrial development.

Industry develops following a more or less well established pattern, that starts with building construction (and related industry); then textile industry (and concomitantly clothing and footwear); light mechanical industry (including plastics moulding, fabrication of common metal shapes, etc.); light chemical industry (including food processing, hygiene products, etc.); light electrical and electromechanical industry (appliances, electrical materials); telecommunications and electronics; industrial mechanical goods, etc.

This enumeration should not be interpreted as a succession of isolated steps in development. There are all sorts of overlappings and interdependence. We refer to the stage at which industry becomes sizeable rather than consisting in one or a few big, more or less artificially implanted enterprises, or in very small family type shops.

Building construction follows practices, uses materials, etc. very tightly tied to local circumstances but the variety in the final products or in materials is limited, which simplifies the problem. The textile and related industry consists mainly on operation of equipment; we exclude the very exceptional case of design and construction of textile equipment. Teaching related to textiles is better tackled through in-service training.

Light mechanical production does require design and this is the area where the economics of production, the choice of materials, the specifications, etc. play a paramount role. In fact, it is evident that buildings cannot be imported (although design can), but the flow of mechanical devices (for instance household items, parts of building such as locks, window frames, heating or ventilating apparatus, ceramics or finishing materials, sanitary ware, etc.) is comparatively easy and not unduly expensive.

Therefore, these are the type products for which it is important to develop design and production capabilities to start with, in the developing countries.

The second area, that develops as a consequence, is that of light electrical and electromechanical industry, which does not differs from the first one, except that it incorporates techniques and devices for processing of energy (usually electrical to thermal or to kinetic). But the equipment is substantially mechanical in nature.

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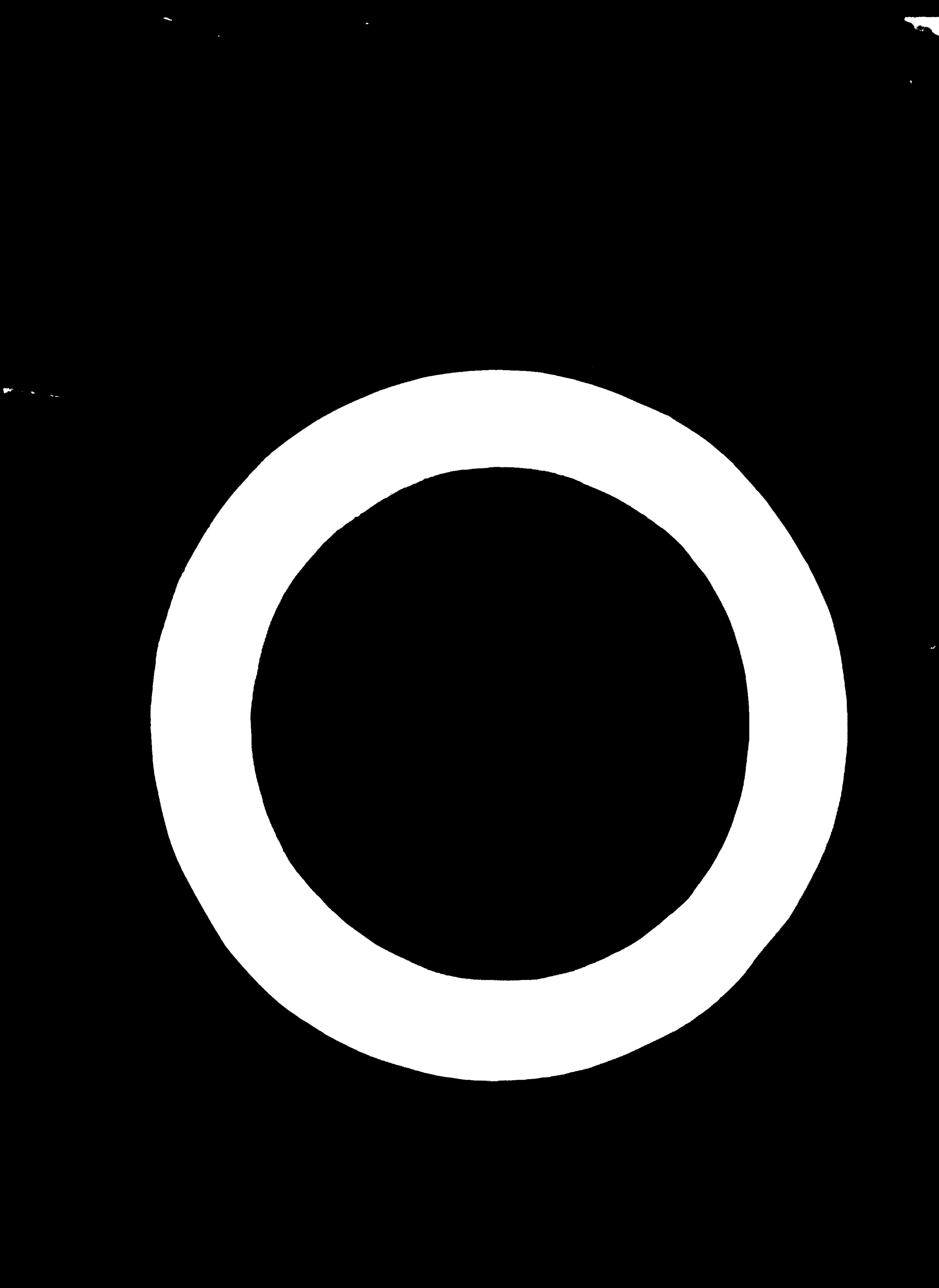
If teaching should contribute to create design capabilities in the developing countries, which is obvious, then curricula can not be based only on imparting technological knowledge. The two additional dimensions of teaching discussed above should stand at a par with it.

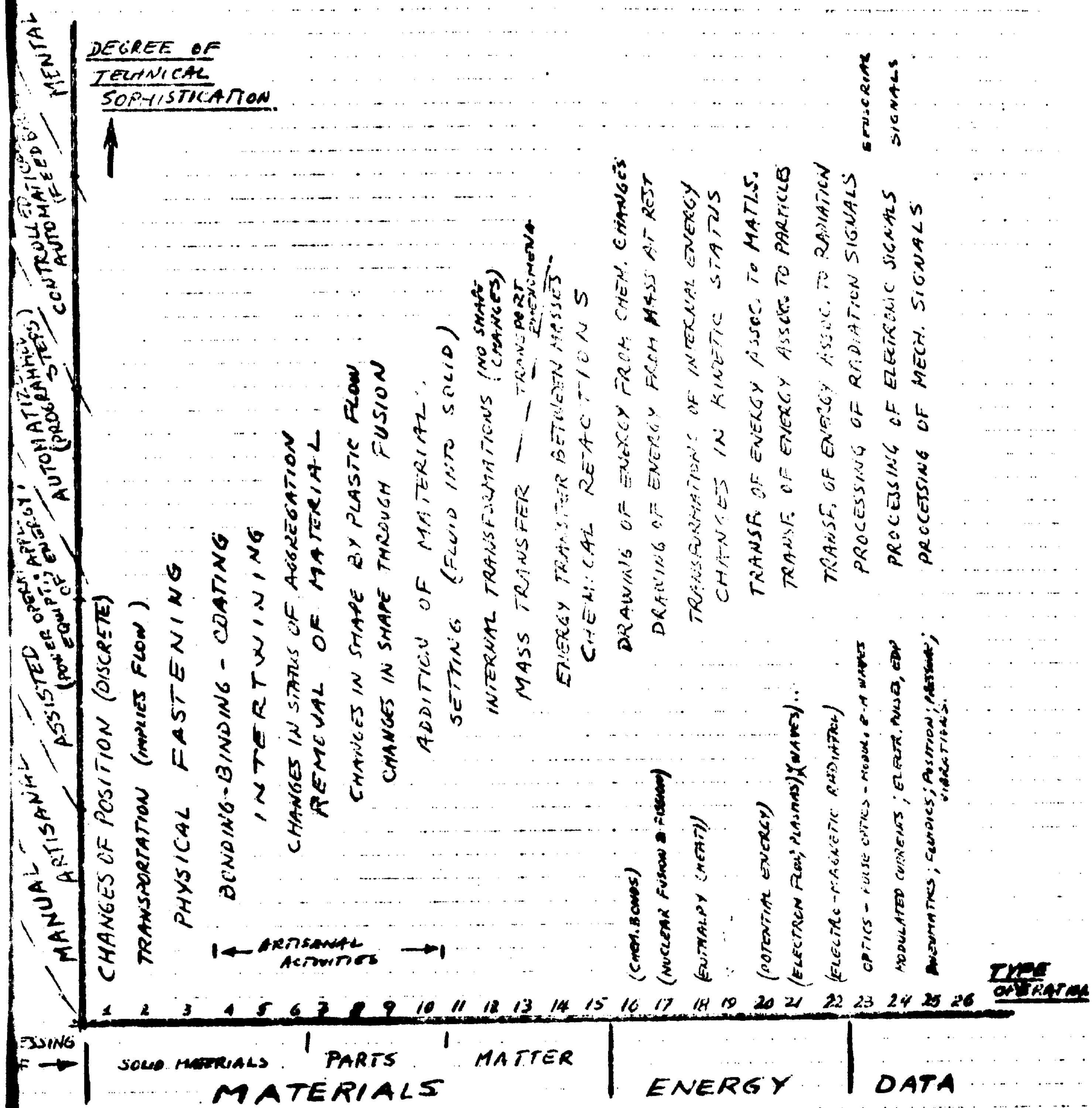
Thus, the studies should include a systematic discussion of modes of performance to which each type operation is amenable. The aim should be not only to give concepts on the matter*, but also quantitative data, criteria for analysis, even numerical methods to perform it. Particularly within the three upper "orders" of activities the technican and the engineer should be able to juditiously decide between manual and highly automated procedures, between the use of general purpose and narrowly specialized equipment, between low capacity, simple equipment and high-speed, complex devices. Should also be able to balance the use of more or less appropriate materials against manufacturing procedures, equipment needed, standardization of parts, reduction of stocks, skills available.

A more clear distinction between functions in industry (third dimension in our analysis), would permit putting emphasis on design at the appropriate levels, and introducing the technico-economic and organisational aspects in a systematic way. In other words, prunning the present curricula at each level from the technical or informative subjects which are of little or no relevance to the "order" of activity at which the studies aim, would permit treating systematically the aspects just mentioned.

To the same end would contribute a rearrangement of the subject matter of purely technical content which could well be done as hinted in the grouping of individual operations discussed above.

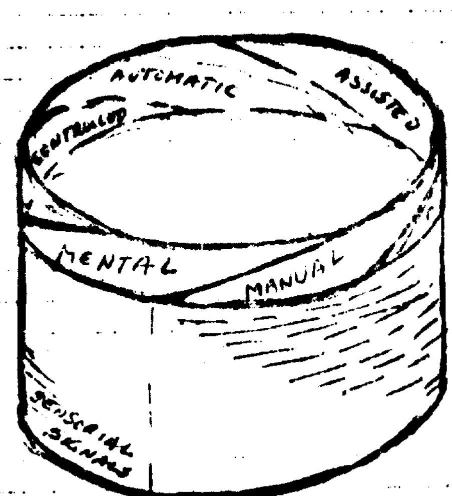
* which often go no further than stating "in medio stat virtus"





ROLE OF MANUAL SKILLS OR ACTION DECREASES →

IMPORTANCE OF KNOWLEDGE AND ROLE OF INTELLECTUAL SKILLS INCREASE →



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