Designing a curriculum for university-level engineering programme

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Engineering design methodology is a well-established, step-by-step process to arrive at an optimal solution to an engineering problem. Similarly, treating engineering educational process at the degree level as a design problem and adopting a design methodology, it should be possible to devise a curriculum which may be considered optimal, subject to the constraints imposed.

The growth in the number of technical institutions both at the degree level and at the diploma level during the last ten years, has not only been phenomenal but is also of serious concern. The concern is not so much with the number per se, but with the overall quality and standards of many of these institutions. Due to increasing opportunities in the job market and good salary structure, the demand for technical education is substantial. These have attracted the attention of private management to start newer institutions, but with poor infrastructural facilities, inadequate planning and lack of academic vision. Since the degrees are awarded by the universities to which the colleges are affiliated, poor-quality institutions get merged with good-quality ones. As the income to the privately managed institutions directly depends on the number of students admitted to each discipline, there has been a proliferation in the number of disciplines where the difference between one discipline and another involves just two or three subjects. Where electives could have easily taken care of these, newer and fanciful departments/divisions/disciplines are created with separate admission strengths. The availability of qualified faculty members, resource materials, training opportunities, etc. has become secondary. As a natural consequence, committees were set up and exercises were conducted to rationalize the course structures and these have met with limited success.

This rationalization of courses, whether it be at the degree level or at the diploma level, depends essentially on the aims and objectives of a formal academic training programme. This exercise involves identification of subjects or courses, their contents, and sequencing in an organized manner, and is commonly called curriculum formulation. To arrive at a rational structure, the objectives of a formal engineering education programme should be clearly understood. The curriculum that is followed in most of the institutions today is a ‘cut and paste’ formulation. Depending on several pulls and pushes, the curricula undergo frequent changes. The present article focuses attention on the formulation of a curriculum for a degree level programme on a rational basis. The steps involved in developing a curriculum are similar to those followed in designing an engineering system.

Asking what engineering is, is similar to asking what physics or chemistry is. It is better to ask what physics deals with or what the subject matters of chemistry are. Similarly, regarding engineering, all professional bodies, including the All India Council for Technical Education (AICTE), convey the following:

(a) Engineering involves professional activities just as nursing is a professional activity and teaching is a professional activity.
(b) These activities which ultimately lead to the creation of physical artefacts, are for the benefit of mankind, and make use of materials and forces of nature.
(c) These resources are to be used economically, i.e. optimum utilization of resources is required.
(d) To do this, a knowledge of mathematical and natural sciences is required.
(e) This knowledge is used with judicious judgement.

All physical artefacts, whether they be multi-storey buildings, supersonic aircraft, orbiting satellites or communication networks, justify this description of what engineering deals with. While a person who practices activities as described above participating in the production of physical artefacts may be called an engineer, many a time, the term ‘engineering scientist’ is used to describe a person having an engineering degree and pursuing research activities. If we were to look at a curriculum labelled ‘engineering sciences’ and another one labelled ‘engineering’, one might infer that there is no science content in the engineering curriculum! In this article no distinction is made between these two curricula, since there is no meaning in using the modifier ‘science’. It is this modifier which made the early authors of the ‘Science and Technology Policy’ of the Government of India state that science includes engineering!

The aim of engineering is to optimize the usefulness of resources to man. Merely producing physical artefacts is not enough. It is the constant effort to optimize the values
of these artefacts that truly represents the nature of engineering. The characteristics of an engineering system depend upon how various physical variables are combined in a design. The ingredients from which the design must ultimately be made are materials, energy, space and time. There are laws which restrict the way in which these variables may be arbitrarily adjusted. Science provides the knowledge regarding these laws. Because of this, engineering activities require a sound knowledge of natural sciences and mathematics.

While the physical artefacts that an engineer produces are for the benefit of mankind, a question that arises is whether moral values should be attached to the products produced. In other words, should the engineering student ignore the existence of moral values? The answer obviously is ‘no’. As a citizen, an engineer will be passing on judgements on a variety of products and materials, similar to those with which he himself will be actively involved. Consequently, engineering education must expose the student to aspects of humanities so that he can identify himself as a member of the human community and act accordingly. Judicious judgement were the words used earlier.

A knowledge of natural sciences, mathematics and humanities alone will not make an engineer. There is a group of subjects common to all branches of engineering that forms the basis or the foundation upon which the superstructure of subjects pertaining to individual branches or disciplines is built. These basic courses are called by different names like core subjects, engineering science (in contrast to natural sciences), etc. Selecting the appropriate ones and accommodating them in a time-bound programme is a difficult part of curriculum design. This is because, the number of subjects coming under this category is not only large but involves arriving at a consensus among the participating faculty members. Since the formal educational programme at the degree level is limited to four years, the tendency or the urge on the part of faculty members belonging to a particular professional discipline or department will be to fill the programme with more number of courses pertaining to their own discipline. This is one of the main reasons for the difficulty in arriving at a consensus. Examples of core subjects are: engineering mechanics, mechanics of solids, mechanics of fluids, thermodynamics, materials science, computer science, electrical science, engineering graphics, manufacturing science, etc. In addition, these subjects have their associated laboratory practices also.

Similar to engineering sciences subjects, another subject group that has recently appeared in engineering curricula deals with management sciences. Since many engineers find themselves frequently occupying managerial positions in large enterprises, an exposure to subjects dealing with engineering economics, finance and accounting industrial and labour relations, etc. has been favoured by employing agencies and engineering students.

As mentioned earlier, the aim of engineering is to utilize and optimize the available resources for the benefit of mankind. The nature of engineering problems is such that they do not lend themselves to unique solutions. Many a time, even the possible solutions will not be obvious. When several solutions are found feasible for a problem, many factors like availability of material, cost of production, weight, reliability, availability of required manpower, time factor, social responsibility, etc. enter into the solution. An engineer has to optimize the final product considering several of these viewpoints. In large engineering projects, for example, communication network, hydroelectric or thermal power station design, etc., which involve several persons from different disciplines, the optimization task becomes a multi-attribute problem of complex nature, posing conflicting solutions. The main point to realize is that the engineering education process should expose the students to problems that do not have obvious answers, do not have unique solutions, and solutions that are found feasible need optimizing to arrive at a final answer. This optimizing process is iterative; where the variables entering into the problem are adjusted and readjusted to get the final answer. This is generally termed as the design process and is a common characteristic of all engineering problems whether they be electrical, mechanical, thermal or electro-mechanical. This discipline of design is the crowning point of engineering education, and the curriculum content and training should be relevant to this important aspect. Generally, exposure to open-ended problems should form a part of all engineering subjects.

A few academic departments abroad are called ‘Department of General Engineering’, whose curricula aim at producing a general engineer not specially trained in any particular professional discipline like civil, electrical, mechanical, etc. These general engineers may become proficient in specialized areas after a few years of practical exposure. There are some good arguments in favour of this practice, but in the Indian context, this has not been accepted. The reason for this is the desire on the part of the employing agencies that the graduate become productive as early as possible in a particular field of activity. Also, our post-graduate academic programmes at the Master’s and Doctoral levels which are also time-bound, demand on the part of the graduates, earlier exposures to specialized branches or disciplines. This means that the degree-level programmes should provide the students with considerable exposure to traditional disciplines like civil, electrical, chemical, mechanical, etc. These professional subjects form the super-structure that is built on the foundation courses which were called core subjects or Engineering sciences subjects.

It was mentioned earlier that one of the motivating factors on the part of private management to introduce a large number of disciplines or branches of study is to ensure a large intake of students. Another reason for this is the desire on the part of the students to have a brand or a narrow branch of specialization attached to their degrees, so that they become readily employable. Experience shows that such narrow branches of specializations soon become
obsolescence of the market demand for them. On the other hand, traditional branches like civil, electrical, mechanical, etc. continue to survive. However, to provide exposure at the undergraduate level to some narrow branches of study which may currently be in demand, a few slots may be necessary in the curriculum to offer them as electives in the final period of study.

Then there is the final year or semester project undertaken by all students. This is the capstone project since the problem chosen for this is not elementary in nature and the solution to the problem may call for a combined knowledge or synthesis of what the student has studied so far. If the problem chosen for this project were to be of a design nature, i.e., involve the steps of a design process discussed earlier in arriving at a solution, it would have been ideal, since the student would then have demonstrated through an example, the objective of the engineering education. Unfortunately, majority of the problems chosen by the students or those assigned by the faculty members, do not belong to this category. Thus it is essential that at least one common course on engineering design be prescribed for students of all disciplines. While preparing their vitae either for a job or for the purposes of higher education, graduating students mention among several other things, their areas of specializations and final year project details. While preparing the project report, they are expected to display their ability to write a technical report and also make an oral presentation before a group of experts, i.e., faculty members. Hence, the final year project, by practice, forms an important part of the engineering curriculum.

Having thus established a large framework within which the curriculum is to be fitted, the question now is: with so many subjects that are to be taught within a span of four years, how shall one go about selecting a few and rejecting a large number of others? If one were to listen only to the demands of the industry, one would soon compile an impressive list of requirements, each of them representing what a particular industry, or often a mere segment of it, cherishes most. If this is accepted, one could fill up the whole four-year curriculum with courses geared to these requirements, to the exclusion of anything else. If one were to assure employment to every student in one industry or another with equal promotional opportunities, then one may seriously consider such a proposal. This is neither possible nor a desirable approach. Industrial scenarios change dynamically that no curriculum can keep pace with their rate of proliferation. Not only that, many industries may even become obsolete before the student graduates! Changes in technology are too fast.

Late T. R. Das, former Vice-Chancellor of J. N. Technological University in Andhra Pradesh, had initiated an exercise called ‘activity analysis’ to find out the types of job and technical activity in which the students were involved during the first three/four years of employment immediately after graduation. The idea behind this exercise was to find out the types of educational exposure that the students would need in order to make them more useful to the professions they would be following soon after their graduation. While this has some merit in making the students employable and productive soon after their graduation, it suffers from the drawback that the education training becomes geared more to the needs of the existing industrial scene rather than based on a better or lasting principle.

While the present needs of the industry cannot be totally ignored, they must be tempered by the requirements that educational training be less specific and more likely to be relevant in the future.

The question now is how should one proceed in the face of so many and such varied demands? We have seen that the curriculum should reveal the following characteristics. These are generally called the attributes of the system, i.e., the educational system which is under design.

(1) There should be a strong science and mathematics stem. The principles and laws of science tell the restrictions imposed on the arbitrary combinations of the physical ingredients that form an engineering artefact.

(2) There should be a strong humanities stem. The engineer being an active member of the society in which he lives, should design the system in such a way that it satisfies the desires of large segments of society and does not offend the values the society has.

(3) There should be a strong design stem. It is important to remember that design is the essence of engineering and it is essential that the design culture be ingrained in the students.

(4) The core subjects which form the foundation for all branches of engineering, should figure prominently in the curriculum.

(5) The curriculum should provide considerable exposure to subjects belonging to the respective disciplines like civil, electrical, mechanical, computer science, etc. These subject fields may come with their own specialization areas of current interest in the form of electives.

(6) As mentioned earlier, there have been repeated suggestions from the alumni and the employing agencies that a good curriculum should have a component dealing with some aspects of management principles.

(7) Lastly, there is the final year project for all students in their respective branches of study. The time allotted for this is usually equivalent to one semester, though the students spend more time on this (during weekends, vacation, etc.) because of the weightage given to it by the employing agencies, postgraduate schools and others.

In addition to the aforementioned seven major attributes, there are two system parameters to be considered. These are:

(i) inputs and (ii) outputs.

Inputs are the elements (which in our case, are the students entering the college) which are converted or modified by the system in question. The output is the product...
produced or modified by the system. This means that the educational process (i.e. the system under design) should transform the student into a finished product having the attributes of an engineer who can actively participate in design, development, and research. The objective of the design exercise is to optimize this process.

Next in the design process come the constraints to be considered. These are important factors which will enable a designer to select a limited number of feasible solutions from a large set of initially identified possible solutions. The major ones are:

(i) Time frame available for the educational process which is currently four years for the degree programme.
(ii) Educational background of the students entering into the system, i.e. input characteristics.
(iii) Faculty qualifications; their exposure to teaching experiences; commitment to teaching; continuing education opportunities; awareness to increasing complexity of the industries.
(iv) Availability of resource materials; library and laboratory facilities; supporting staff; industrial training opportunities.
(v) University examination system; evaluation procedure. Limitation on funds, buildings, faculty strength; student-teacher ratio.
(vi) Employment opportunities; expectations of industries, etc.

Now comes the development of criteria for the selection of the subjects that satisfy the seven major attributes of the system. If one compares the subjects that were being taught, say, about thirty years ago with those that formed the curriculum about ten years ago, or those of today, one feature that stands out prominently is the survival of those subjects or topics which deal with laws or principles which have wider applications, which affect more of its fields, and explain a greater variety of situations. This means that in the engineering curriculum one must give preference to those subjects and methods of inquiry which are common to most engineering activities and have a greater bearing on the future of engineering.

Subjects that are of relevance to engineering are many; and in our anxiety to expose the students to as many as possible within the available time, we tend to compress or ignore important details; for example, assumptions made in deriving certain equations or formulas. Another tendency is to resort to the familiar statement, ‘It can be shown that’. Many instances exist where equations are used in situations where they are not valid. In the process of selecting the subject content, concept development, continuity of presentation and relevance to engineering constitute important aspects. It is also necessary that the course contain enough of the material with which the engineer operates; i.e. necessary and sufficient amount of information. This particular aspect provides the upper and lower bounds for a subject content. Further, at the end of graduation, the student should be able to take up a suitable job or go for postgraduate studies. If one were to examine a well-designed curriculum, one should be able to see a continuity in the flow of logic in movement from topic to topic, and in the build-up from subject to subject.

Finally, there is the discipline of design which is the crowning point of engineering education. Design is a logical process with clearly defined steps that are applicable to all fields of engineering endeavour. This aspect has been stressed repeatedly in this article since it is one of the most important components missing in our curricula. Majority of faculty members in our technical institutions feel diffident to teach the subject of design because of the lack of examples they can draw from their own experiences. While the subject of design may not find explicit place in the curricula of several Western technical institutions, a culture exists in those countries which promote competitiveness, desire to produce new artefacts, improving upon existing gadgets, starting new enterprises, taking risks and surviving, and a host of similar qualities among scientists, engineers, technicians, medical practitioners, etc. It is this culture which is lacking in our society. The solution to this does not exist in copying and pasting only those subjects taken from Western curricula that are convenient to practice and teach, but to make a deliberate and sustained effort to teach, promote and ingrain the design culture in our student community.

Optimization is the most difficult part of curriculum design. If all the constraints imposed could be expressed in numbers, the optimization process may not be a special problem. A majority of constraints are intangible, and they can at best be expressed only in qualitative terms. In such a situation, an optimum system is judged as one which satisfies to the maximum possible measure, all of the constraints imposed on it. In practice, this exercise is carried out with the participation of all faculty members of the institution. Prior to this, the rationale for design should be agreed upon by the participating faculty, as otherwise, discordant and conflicting views will emerge. Generally, as experience shows, a new curriculum design involves a time span of more than a year. It is a detailed design process which cannot be rushed through. Instances are many where persons in charge, like the Vice-Chancellors of newly formed technological universities, have issued orders that a ‘rational curriculum’ be formed in a ‘two-day workshop’!

In comparison, several IITs have taken more than a year to bring in moderate changes in the curricula they have been following for many years.

While participation of all faculty members is important, one should expect that opinions differ sharply among the members. Conflict in opinion is essentially due to the fact that a large number of subjects belonging to professional disciplines have to be left out because of the so-called core subjects and common subjects.

But, this is an exercise that has to be undertaken and a consensus obtained. John N. Warfield, the well-known sys-
tems specialist, has developed a set of methodologies called 'consensus methodologies', which permit efficient generation of ideas such as goals, objectives, etc. by participating groups. These methodologies have histories of successful application which are available in the open literature. Further, these methodologies are ably suited for open dialogue, and for equal decision-making powers for all participants, in order to stimulate consensus. Adopting a few of these consensus methodologies has two advantages. One, a good and acceptable curriculum will emerge; and two, knowledge and practice of these methodologies in situations involving management and planning in general, is highly profitable for all faculty members.

While designing a system like the present one, several factors (or attributes) in addition to the ones mentioned may be brought in by the participating faculty. For example, aspects of communication skills or minimum proficiency in English (because of the medium of instruction), may be additional factors. In the IIT system, these are considered as deficiencies or shortcomings in the input characteristics of some of the students admitted; and make-up classes are conducted outside the regular hours. Another question that is gaining importance is, whether the curriculum that is being designed should meet the expectations or the requirements of the concerned boards of accreditation. In USA, the accreditation board has indicated some broad guidelines. But this is a country-specific factor. The Undergraduate Advisory Board set up by AICTE has attempted to provide as a guideline, the apportionment of time in terms of credits for basic sciences, basic engineering, professional core, professional electives, humanities and management, and project. In addition, several models from IITs, NITs, etc. are readily available. Here, a deliberate attempt is made not to mention any of these as a model or as an example, because in applying the design methodology, one important statement to remember is: 'In the process of obtaining an optimum solution to a problem, the biggest handicap is the early availability of a solution'. Every student undergoing a course on 'design methodologies' is advised to remember this. Following the design methodologies, when several feasible solutions are obtained, the process of optimization takes into account factors such as the ones mentioned earlier. It is well to remember, that designing is an iterative process in which adjustments and readjustments are made until the designing team is reasonably satisfied with the final solution.

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