Why should engineering educators in search for quality and excellence look beyond learning outcomes to refer to a global "model"?

Table of contents

This proposal of a global model for engineering education is the outcome of a project, subsidised by the European Union, whose aim was to define a new label for excellence in engineering education in Europe (QUESTE). It appeared necessary during the project to elaborate a comprehensive frame which could be used by all engineering programmes, to describe their variety, and to give a solid ground to assess the achievement of their objectives.

The value of this proposal has been confirmed through an analysis of a wide range of existing practices, such as the CDIO model and the reference frameworks used by the three Dutch technical universities.

It may be considered as a smart tool, for the management and external promotion of engineering education, but also as an attempt to cast a new vision on an activity which has kept years after years a rather traditional figure.

Working paper - Claude Maury

Engineering education replaced in its historical dimension

The historical emergence of engineering education

Since the beginning of the 18th century, professional schools have been created all around the world to give future engineers the basic scientific and technical knowledge, which was required by the new developing industries. Step by step all these institutions have gained importance (x30 more graduates between 1850 and 1910 according to Bairoch) to become a full segment of Higher education, being organised in technical colleges, technological universities or schools of engineering in comprehensive universities.

Engineering education, which is now recognised as an important part of higher education, is considered to have a key-role in our economic development.

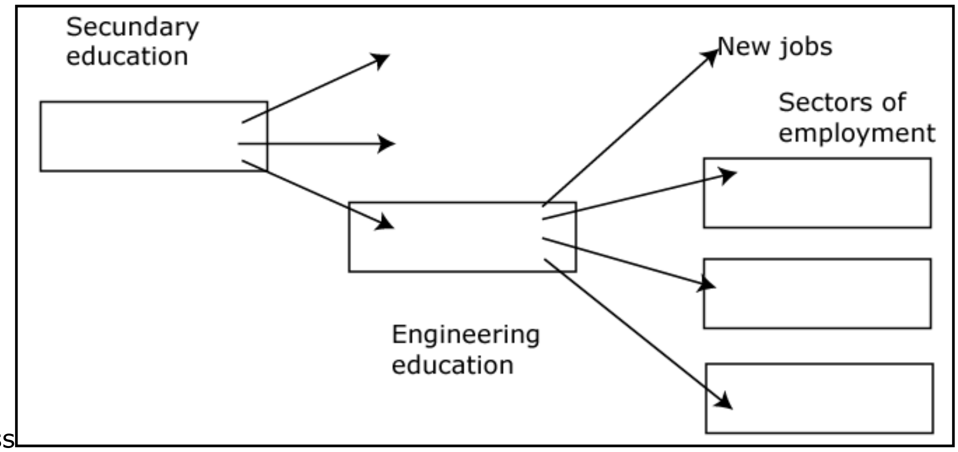
It would however be a mistake to understand engineering education by itself as a complete preparation to the engineering profession. Engineering education, as we understand it, appears only as one phase of the preparation of the engineering workforce, whose qualification is built up in a sequence of three stages:

- through a basic scientific education (in High Schools) providing a base for future studies (with critical requirements in maths and basic science)
- through an actual engineering education (in technical universities or engineering schools) providing graduates with various resources such as complementary sciences, advanced technical knowledge in one field, elements of methodology, corresponding to a pre-qualification phase,
- through a complementary training and personal development to reach adequate qualification in a defined professional context.

The importance of the first professional period is underlined by the common practice, f.e. in the UK, and in several other countries of the former Commonwealth, to recognise engineering graduate as plain professionals only after a complementary training period of 3-4 years.

The optimal management of this process is not so easy, since it does not obey to a pure linear logic. At each level, the future of graduates is not fully determined: any engineering graduate is free to take a job in a wide range of sectors and functions, any scientific scholar keeps the possibility to enter different type of higher studies.

A three stages



process

How to ensure the adaptation of the educational process?

In a rapidly changing context with emergence of new technologies and opening of new markets and of new types of partnerships, an adequate preparation all engineering graduates to their future jobs is an actual challenge. The continuous adjustment of the engineering syllabus is crucial, without speaking of the need to check the relevance of all options .

A common view at that point is to reduce the issue of the adaptation of the educational process to a simple and strict adequacy to the expectations of the professional milieu. In this scheme engineering education should strive to adapt itself continuously to new professional expectations, and basic scientific education should in the same pace adjust itself to the continuously updated requirements of engineering education.

Things are not exactly going that way for several reasons

- As we already noticed, engineering courses lead to a wide range of professional positions, each of them sending different messages to the educators. Corporate firms refer mainly to jobs defined in their own context, while engineering schools are supposed to prepare their graduates to a much wider scope of professional positions (see figure above)
- Corporate firms feel frequently difficult to express their views on the future, beyond a rather short term horizon (6 to 18 months sometimes) and often adopt an idealistic approach, if not contradictory, expressing for example the wish of fresh graduate with a substantial experience of 3-4 years…!
- the forecast of technological breakthrough is not the monopoly of industrial teams: prospective views on technology will be easier to define in a balanced debate, with the participation of academic researchers.

Despite of these difficulties the issue of adapting courses is usually addressed in a pragmatic and balanced way with the double concern to meet short terms expectations (adaptation to immediate expectations) as well as to keep an attention on long terms evolutions. In all industrialised countries educationalists have organised various forms of dialogues which have allowed to defined and update regularly concrete guidelines.

Beyond this day to day internal management, accreditation process are exerting a periodic control to verify that common standards adapted continuously have been met

In the last 15 years, the new trend, which has now gained a world-wide expansion, has been to put emphasis on an analytical approach based on lists of skills and competencies, which are supposed to be regularly updated.

The growing role taken by "learning outcomes"

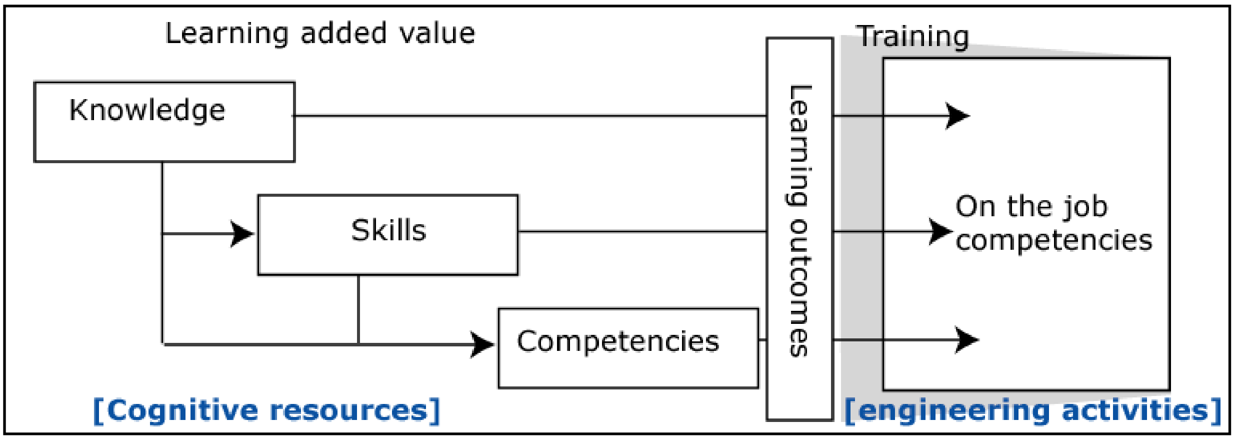
A new view on qualifications

All along the 20th century, the tradition has been to consider qualifications as the expression of the general aptitude of anybody to take a specific job, with separation of classes in relation with the expertise and to the level of responsibilities. In that sense the qualifications were mainly relative to a position in a working organisation.

In the last twenty years a new glance has been born on this matter, which has led to a quite different approach, with a primary attention given to the individual aptitudes to face certain situations (each aptitude being then considered as a competency). In that sense qualifications are now viewed as a sum of abilities to face a series of various situations.

This adoption of this analytic approach has numerous advantages, since it enables a much more flexible management of human resources. To deal with a project the issue is to gather a sum of competencies. To qualify somebody for a peculiar job, a short training session may be enough to give him the requested competency .

Schematic description of the qualification process



In a natural move, the new approach has favoured the idea to attach to any profession-oriented course a formal specification, not really expressed in competencies (since competencies can be acquired and proofed only in a professional situation) but in terms of general capacities and skills associated to a targeted professional profile.

This is the meaning of the interest born to list of "learning outcomes", which are now used to control the conformity with standards.

A widespread use of list of learning outcomes

The use of list of outcomes (or frameworks of reference) is now a widespread practice , which have been adopted by accreditation bodies (initiated by ABET in 1999 through EC2000 specifications) and now proposed everywhere as a pattern, especially in Europe where this disposition has been adopted as common rule in the Bologna agreement (Each HE degree is supposed to receive a description in terms of learning outcomes).

The use of outcomes lists as specification for engineering programmes appears now as a an unavoidable tool to improve engineering education quality and to fine-tune it to economy expectations. For that reason all accreditation bodies are publishing such list, which they use as tools of control (ABET, ASIIN, CTI, EURACE)

Such descriptions of programmes, appear clearly superior to raw syllabus, and as a smart way to guarantee a better chance to acquire rapidly expected professional skills.

Working with lists of outcomes has indeed clear advantages…

This analytic approach, which, to a certain extent, relates objectives of a course to professional abilities, has numerous advantages:

- it encourage academic managers to define taught subjects and learning methods (curriculum development) in better connection with companies expectations, that brings more consistency in internal choices and limits common trends to focus discussions on contents of courses,
- it brings a better readability of educational objectives for end-users (as for students themselves) which makes orientation debates much clearer.
- Reference frameworks helps students to have a much more concrete idea of their progression within a programme

It is obvious that general frameworks of reference, expressed as a list of expected outcomes, are useful tools for accreditation bodies, to which they offer a kind of check-list to guide their control.

…but is has also limits

Although being a clear progress on traditional descriptions based on subjects, the "outcomes approach" demonstrates various (and sometimes serious) limitations

- There is a conceptual gap (a duality) between presented list of learning outcomes and actual programmes, (mainly dedicated to the teaching of subjects) which forces to accept a double description and two different ways of understanding what is done in an engineering course. Attempts to adopt matrix of correspondence are not really convincing…
- Another annoying aspect of this duality is the difficulty to assess expected outcomes :
  - assessment methods are hard to be defined (outcomes remain too general to be assessed and rely more on self assessment)
  - no choice has been made between a pass or failed approach and a more flexible way to combine marks (compromise asked by the student body).
- Whatever efforts are made, outcomes lists have don't grasp the whole reality of educational processes in depth: the role of the institutional environment (department, student community) is left in the background, and important dimensions (values, fostering of individual attitudes) are more or less forgotten.
- Lists of outcomes are defined in an analytical spirit. The list give the impression that the final efficiency may simply result of a sum of elementary capacities[1] .

Other objections may be raised, which may be corrected:

1 that is not true: indeed a more realistic model is to relate global efficiency to a product of three variable, the first being the competency, the second the personal attitude, and the third the motivation within a work organisation

- list of outcomes are focusing on immediate expectations and don't integrate well what is needed to ensure a continuous adaptation of the programmes
- Even defined in relation with the workplace, outcomes lists remain often much too general to match with professional needs (job descriptions), which give a much larger place to precise abilities.

Since the sensible choice is made to rely the expression of learning outcomes on quite general formulations, they appear more as guidelines, than as operational objectives[2].

What for a wider frame for engineering education?

The need for a broader model

When you consider that the ultimate ambition of any educational process should be to build up global efficiency in actual business life, it is not so obvious to say that the challenge can be strictly be met through the achievement of explicit learning outcomes, whatever logical this position may appear.

A simple model of global efficiency can be to consider it, as the **product** of three factors, the first being competencies, the second personal attitudes and the third the capacity of the management to draw advantages of existing potentialities[3] (level of autonomy , motivation, group efficiency).

Collective performance = motivation x attitudes x competencies

Whatever you may say to adjust this raw formula, it underlines the fact that the ultimate efficiency of education has to be considered in a larger frame.

This is the rationale to adopt in a so-called "model" approach, and to shift towards a broader frame, including institutional aspects, such as strategy, reactivity, values and other dimension such as students personal development. In that sense a model will become the frame for any institution to give a concrete expression if its ambition, and a support for students motivation.

Key points

In comparison with the classical learning outcomes approach, the model approach put emphasis on new dimensions:

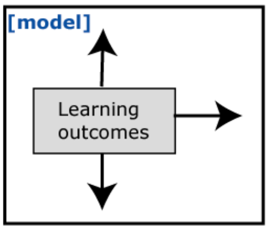
- Any course has to be replaced in its institutional frame, especially in its relations with strategic options (targeted profile, pedagogical options), permanent values and global vision of the role of science and technology in modern societies,
- Since their first meaning is to serve a strategy, educational objectives are supposed to be expressed in a rather free way, with an attention borne beyond the classical expression of learning outcomes to complementary skills (such as study skills and comprehension of the industrial context), and an open approach of assessment (with a place given to students self evaluation)
- The educational mission has to be widen to the development of personal attitudes, whatever aspect it covers intellectual, personality, values, with the idea to draw the most from individual talents.

2 This is for example the case of the Dublin indicators, which have been proposed to distinguish the two first Bologna levels

3 To be related to talents

Main components of a model

A model may be simply understood as an extension, taking into account new dimensions, of



classical frameworks of reference, which are focusing on learning outcomes.

To avoid the risk of of ramping complexity, the sensible option is to build models to address four general dimensions of engineering education

1. Identity features and strategical options (at the institutional or departmental level)
2. Educational objectives (learning outcomes and complementary conditions at the level of a specific course)
3. Student personal development
4. Control and steering of the educational process (management)

These four dimensions are introduced below with major subdivisions and general comments.

Identity features and strategical options (4 sub-items)

Four sub-items may be isolated, which are all bringing a direct contribution to the identity of the institution:

- **Vision of engineering today and in the future within a modern society**

Such a vision constitute a background for all reflections on engineering education. Even based on objective observations (facts, analysis of experts) it will keep a subjective dimension to a certain extent: it seems however important to open an internal debate on this issue, to better perceive the reality of alternative routes[4] for development and role of engineering, through consultations of the corporate world and analysis of prospective studies. Such visions will be often shared by groups of institutions, if not all by the overall engineering community, with the use of all reflection developed in a national context (Academy of engineering).

There is for example two options for the future of engineering:

- either engineering will be considered as a kind of toolbox to solve certain types of problems
- or engineering (and engineers) will be accepted as a full partner for the identification of problems to solve

Debates on vision may interfere with ethics issues and push towards specific strategy (sustainable development, water resources,…). It may also lead to developments on ways to adapt engineering to very poor countries…

- **Targeted engineering profile**

[4] The idea that there are perhaps several routes for middle term development humanity is easier to grasp in the present global crisis, which is everywhere raising basic questions about our common future

This issue is crucial for the right definition of an educational programme. Two extreme options are possible:

- either the targeted profile may be quite well identified (with links to some jobs descriptions) that lead to a professional -oriented curriculum, with short term advantages and some limits (rigidity).
- or the targeted profile may be kept quite open, with an emphasis put on general capacities and resources (ability to learn, to address complex situations…),

Choices on profiles have to be confronted with actual positions of former graduates. They may be prepared by joint committees with firms.

- **Educational strategies**

The increasing importance of strategical issues is linked to the fact that higher institutions are more and more in competition with the others and left free of their choices, as far as they are consistent by themselves and with their human and equipment resources.

In comparison with list of learning outcomes, which express immediate objectives, shared by all institutions as far as they are relevant for accreditation processes), strategical options reveal a willingness to differentiate from others and to follow a specific approach.

Strategical objectives may be developed in a hierarchical structure, starting from general items to go to more detailed ones. It seems nevertheless sensible to ensure that there are not too many strategical options, since they must be treated as priorities.

Strategy may be defined as internal choices (proactive attitude) or as answers to external solicitation (reactive attitude).

Examples of strategies related to internal choices (expression of an identity)

- Special stress on future adaptation of graduates (strong scientific base, methods, opening, ability to address complexity…)
- Fostering of an international dimension: mobile engineers
- Specific stress on personal development of the students
- Stress on specific professional profiles (f.e. Architect, client manager, marketing…)
- Fine mastery of technological aspect in one domain
- Stress on the interdisciplinary approaches and on opening on other kind of knowledge (Law, social sciences, economy…)
- Special effort to develop an innovation spirit
- ………

Strategies related to external priorities

A second form of strategies is constituted by the translation of external mainly public policies. Several examples may illustrate such cases

- New attention to sustainable development (public injunction)
- Urgent need to train engineers in nuclear engineering (private and public injunction)
- New attention to give to OSH aspects (occupational safety and health)
- How to encourage students coming from handicapped milieu to choose engineering studies

All these strategies will be defined through internal debates and decision making. But their realism and consistency may be checked through the effects they have on learning outcomes.

- **Values**

Although scientific circles may consider the reference to values as a bit formal, it has indeed an importance, since it has an influence on all other actions. A declared attachment to some value seems indeed as the best way to support an ethic dimension in engineering education, since the example has to be given by the institution itself.

The definition of values may be considered as purely internal. Their expression contribute to unify all energies. Example

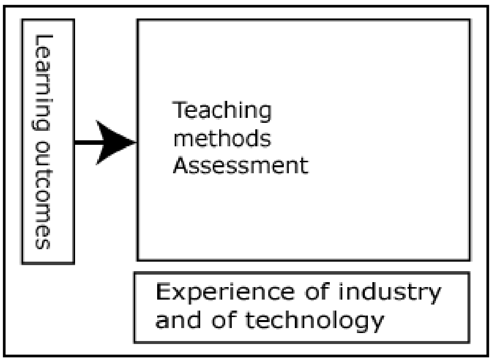
- belief in scientific methodology (association of rigour respect of experimental outcomes, controversy debates)
- importance granted to communities
- solidarity with the rest of the world
- ………

Educational objectives (learning outcomes)

It does not seems necessary to elaborate much on learning outcomes lists, which has become today a quite common issue. The insertion of such lists in a model brings the possibility to widen their scope and to stress especially

- on educational objectives (slightly beyond learning outcomes) and study skills
- on elements of adaptability
- on the solidity of bases

	bases to master before starting	**Expected outcomes** immediate aims	skills for the future (**adaptability)**
Knowledge	Bases of sciences	- scientific knowledge, - technology, - mathematics	Ability to master new knowledge, ability to transfer
Methods linked to practical and contextual actions	…	- Art of engineer, design, industrial management - Scientific research	opening to new domains
Transverse skills	…	communication abilities	transculturality

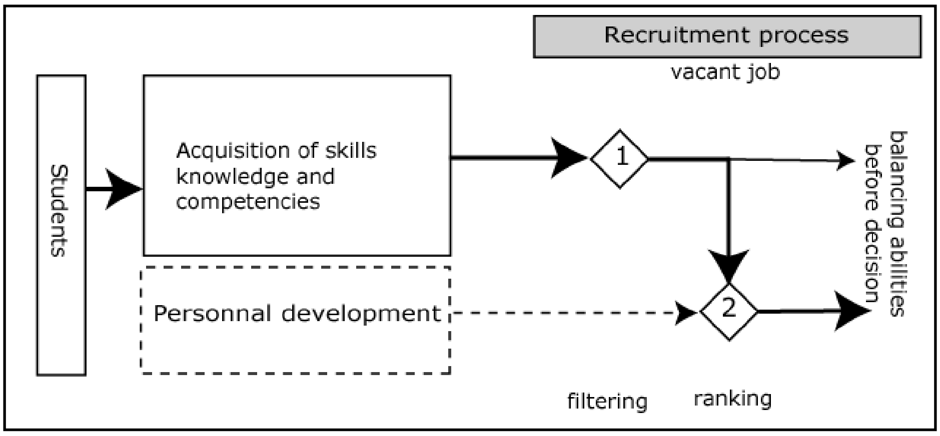


A crucial aspect, which has been addressed by the Dutch document, is to set up of list of outcomes

- which is understandable by faculty
- which may be translated into concrete choice
    - subjects
    - pedagogy
    - assessment

Students development

Although student personal development is not directly assessed, this dimension plays an important role in the appreciation of young graduates by companies and in the future efficiency



of engineering graduates. This is a good reason not to stay passive.

This concern may be split into three main dimension

- Education of mind (curiosity, rigour, autonomy, ability to reason, judgement)
- Personal commitment (leadership, resilience, mobility
- Ethics (respect of the others, moral sense)

Student development relies to an important extent to external activities (creative activities, junior consulting, animation of student life). Il may be supported by dialogue with coaches

Control and steering of the educational process (management)

This dimension takes two concrete forms, the first dealing with quality insurance, the second around the updating function of the model

- **Quality insurance**

The increasing interest borne to quality procedures has to be understood as a direct consequence of the growing autonomy of all educational institutions, which imposes new forms of control. This control has two sources of inspiration: conformity (the main idea being to check the conformity of actual achievements to announced engagements) and performance. It takes different shapes

- The development of an insurance quality relying on a self-assessment procedure
- Periodic assessment by specialised agencies based on performance indicators

A key point is the choice of descriptors or indicators, which have to be good compromise between fidelity and ease of use.

- **Policies adjustment procedures**

The so-called policy adjustment procedures is supposed to provide elements

- to update the strategical options (What for, = finality)
- to adjust the objectives and methods (What we do, how we choose to do it…)

It will relies on an actual openness on environment, which is always, more or less, a source of perturbation, and taking benefit of dialogues with the corporate world and of some feed back studies. Technically two main questions have to be solved:

- How to get the right messages from a communication with the external world which remains always noisy and linked to short terms problems?
- How to use alumni networks?

Some complementary comments on models: how to use them?

Models and accreditation procedures

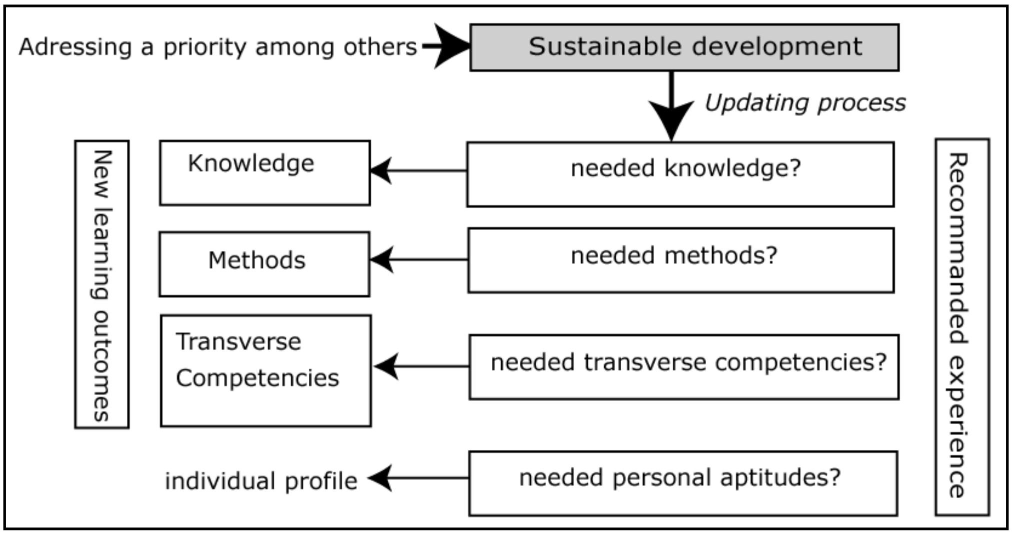
Although accreditation bodies are more and more using lists of outcomes as a privileged analytical tools to check more easily conformity with standards, the decision to accreditate any course cannot be granted without a global judgement integrating most, if not all, elements of the presented model (strategy, updating process, quality insurance, students development…).

Accreditation bodies may be seen as support of kinds of "basic" models, each institution being free to develop its specific model around the basic model. Coexistence of this two views of models should be peaceful relationships. However two risks appear

- Accreditation bodies may be tempted to give a growing importance to outcomes by making the learning outcomes lists more and more detailed and demanding , and building up an unrealistic figure of what should be the ideal engineering graduate.
- Accreditation bodies may unconsciously become more prescriptive (presenting what they see the best options in models as norms) yielding a preference for a peculiar model, intended to become the unique solution to train engineers.

Fortunately, models are build to regulate years after years the casual life of institutions, when accreditation remains a periodic procedure and don't pay attention to individual students.

Connection between strategies and outcomes lists



The presented scheme illustrate a very common situation for courses administrators. A recurrent concern is to translate a general policy priority into learning outcomes requirements.

Differentiation and efficiency

A clear advantage of models is to provide a frame for the expression of a willingness of differentiation. But many of the options (strategical) are based on declarations, and don't pay much attention to structural features, such as

- higher resources
- “better” teachers
- “better” students

An important issue is to see how to neutralise this attitude?

The only sensible way is to introduce smart indicators on the outcomes of the programmes: time to find a job, suitability to the studies, salaries…

Summing up

The starting point of the proposed model for engineering education is to see any engineering programme, more than an educational process precisely defined in an analytical way, but as the production of a social entity (the educational institution where various stake-holders interact, such as faculty or students) and as the expression of its capacities, history and values and strategical choices.

Even if it remains still acceptable (and interesting) to describe and to characterise a programme through a list of features (f.e. taught subjects) or objectives to achieve (learning outcomes) or indirect achievements (employment, professional performances), we propose here to balance this analytical approach, which infers a kind of mechanical relationship (one property being an answer to an expectation, with a kind of adequationism) by a more systemic (holistic) view, emphasising more upon strategy and reactivity.

Our model has to be understood as a meta-model, offering a common description framework for more specific models, with the capacity to well translate their diversity.

This plea in favour of a model approach may trigger various reactions. It may be seen as an attempt to develop a quite formal description, if not cosmetic, without any clear added value, or on the contrary as an opportunity of a deep change in the way we see engineering education.

Arguments may be found in favour of the second options, in its utility and its indirect effect on the status of engineering education.

The three main utilities of the model

The adoption of a model as a general frame for engineering courses has three main utilities

- It may be considered as a self description tool, providing an efficient support for communication (and promotion?) policies and a possible base for a typology[5]. It may be presented as a contribution enabling a better understanding of the reality of engineering education, beyond a better transparency. Clarification will be higher if several institutions accept to share the same model and the same wording.
- It may be seen as on opportunity to check internally the consistency and the realism of all options (taking into account data on resources) and as a tool for internal management as kind of check list for educational managers, who are eager not to forget anything (place given to long-term options, consistency) and especially to check
    - quality
    - permanent adaptability
- It may be used as the base for an external judgement In assessment procedures attention will be given to realism and consistency (Resources/ choices) and to existing gaps between objectives and actual achievements. It may help to the granting of a label.

Models are helping to cast a new glance on engineering education

The importance which has been given in the last years to competencies have developed the idea that an engineer could be perfectly defined as a man having certain abilities (that is true in that direction) but also in the reverse (abilities providing a perfect description that is not true). As soon as the postulate to identify engineers with a set of competencies is accepted, the role of engineering education becomes purely functional, and centred on the acquisition of analytical abilities. The challenge for engineering education is then reduced to the best execution of a defined book of specifications.

The adoption of a so-called "model" approach correspond to a shift towards a "culturalist" view of engineering education, where

- the education process cannot be separated from the historical evolution of an institution and of individuals, and of their values.
- an accent is put on the freedom which is left to institutions to find their own way

From a competencies oriented to a profile oriented approach

The main feature of the proposed meta-model are

- to analyse any programme in close link with the supporting organisation (social entity).
- To give a first rank attention to the motivation (why) and the ambition (what for) expressed of the supporting organisation. This finality would include
    - The underlying vision of the targeted engineering profile (engineer in general, specific profile)
    - A presentation of specific ambitions and local options (strategies)

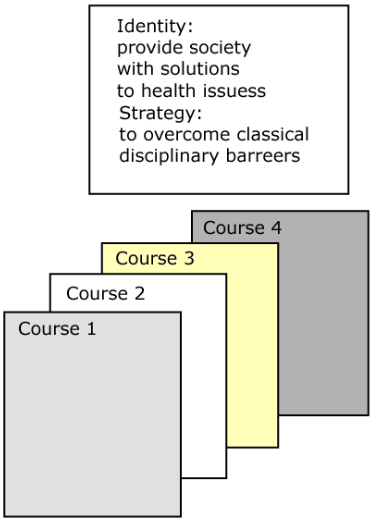
5 to define the bases of a suitable typology it would be interesting to define “landmarks”

- Reference to values

Models as help to redefine engineering education

Since they are putting emphasis on profile strategy and visions on the future economy, models may be helpful to define new approaches of engineering education, perhaps more of engineering departments more or less detached from disciplinary views.

For instance new structures of education could be constituted with the finality to develop skills and competencies connected to health, with an association of faculty in biosciences, in



mechanical engineering and in economy.

CDIO as an example of a global model

The general principles which have been exposed to define a model are back-up by the example of CDIO, which appears to illustrate what a model can be, for a specific engineering profile.

CDIO in 12 basic points

CDIO is an original approach, which has been developed by MIT and some swedish universities to provide engineering educators, with a set of global guidelines, to improve the quality and adequacy of their courses.

Understood as a model, CDIO refers to 12 main points

1. An engineering graduate has to be prepared for the whole product life (conceive, develop, industrialise, operate)
2. Courses objectives have to be expressed in terms of learning outcomes, and assessed in that logic
3. Courses have to be understood in their global meaning, not as a set of lectures covering various subjects
4. Before engaging in engineering studies, students are invited to follow introductory courses on engineering activities (understanding of the context)
5. A significant place (20% of study time) has to be devoted to projects (engineering graduates must be trained to realisation)

6. Any engineering course has to be linked with specific technological area (linking theory and practice)
7. A special care has to be given to interdisciplinary approaches
8. Students have to actors of their education (active pedagogy)
9. Faculty must be encouraged to have an actual engineering experience (understanding of the environment)
10. Faculty must receive support and assistance to develop active pedagogy
11. Care has be given to the definition of adequate assessment procedures
12. Courses must be assessed regularly through surveys among students and companies

CDIO as a model

CDIO may be clearly considered as a model, covering strategic aspect, objectives and practical rules

- it defines a course beyond the presentation of a list of learning outcomes (a special stress is put on the importance to keep o global vision)
- it sets a link between education and an engineering profile, and underline the importance to give new students a view on engineering activities,
- it gives a place to general values
- it expresses rules for teaching itself (active pedagogy)