THE ENGINEERING OF ENGINEERING EDUCATION: CURRICULUM DEVELOPMENT FROM A DESIGNERS POINT OF VIEW

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ABSTRACT. Engineers are basically designers. They have a set of powerful tools at their disposal for creating robust and reliable technical systems. The paradigms of design methodology and systems engineering appear to be enlightening for both analysing existing education and designing new education.

Keywords: curriculum design, systems approach, output oriented education, assessment

1. Introduction
Engineers are in fact designers. Two important paradigms in design are a distinct methodology and a systems approach. It is surprising, that these paradigms are seldom put into full practice when it comes down to the development of educational programmes or curricula. In this paper it will be discussed how a systems approach and design methodology the can help us to structure such complex issues as (engineering) education.

2. The systems approach to education.
2.1. Introduction
The concept of systems has been a great help in structuring and organizing the world around us. Not only in the “hard sciences”, but also in medicine, biology, politics and economics the systems approach has proven to be extremely useful. A system can be defined as a part of the real world, conceived as being an entity with well-defined interactions with its environment. If the system is defined and described in whatever way, we may refer to it as a model.

Fig. 1: The system in its environment

* Now retired
The impact of the environment on the system (dotted arrows in Figure 1) is considered to be the input and the impact of the system on the environment (solid arrows in Figure 1) is considered to be the output (Figure 2).

![Fig. 2: Input and output interaction](image)

This leads to a more structured way of depicting a system as is shown in Figure 3.

![Fig. 3: Formal representation of a system](image)

The systems approach is used in both analysis of the existing world and synthesis of ‘a new world’ (artefacts, procedures, services). In analysis a part of the real world is considered as a system and the interactions with the environment are experimentally verified. This is the application of the systems approach in science, economy, physiology etc. In technology, however, the systems approach is used to design something, that doesn’t exist yet. The interactions with the environment are intentional and can only be estimated by simulating the system, but can be ultimately verified by realizing the system. Interactions with the environment in this case are somewhat more complex and consist of desired (intentional) interactions and spurious (unintentional) interactions (Figure 4). Obviously, the simulation step is highly important in order to avoid any undesired behaviour before realising the actual system: simulation can help us to predict the behaviour of the system once it is realised.

![Fig. 4: A system with unintended interactions with the environment](image)
In education we have to design educational systems. Simulation in its mathematical or technical sense is usually very difficult since it involves people. This means that other ways of predicting its behaviour should be employed. It can be observed in practice that many educational systems (programmes, curricula, courses) are designed and implemented without a thorough prior analysis (i.e. estimation) of how the system will work once implemented.

2.2. Basic descriptions of the educational process
Education can be considered as a process that transforms a student into a graduate student. An important characteristic of this process is its time delay. The input and output quantities are attributes of the student and can be described in terms of knowledge, skills, understanding etc. (Figure 5).

![Fig. 5: Education as a transform of the students’ attributes](image)

The process itself could be described as all activities of the institute of education such as giving lectures organising laboratory experiments. In this context the student is rather passive. He/she has a number of features: by the educational process these features are changed into other features. This is a rather traditional though not at all extinct approach to education. Many teachers still think it is their main duty to transfer their knowledge to the students. In this view the accent is on teaching, rather than learning. Presently, it is more common to assume that knowledge is not transferred but that the learner himself constructs knowledge on the basis of prior knowledge and additionally acquired information. The information can be acquired from written material (books), lectures, experience (laboratories, projects). This view is referred to as constructivism (e.g. Jonassen et al., 1998). In this vision the student plays an active role. As a consequence, Figure 5 can be modified into Figure 6, in which the process is a learning process with the teaching as a facilitating precondition.

![Fig. 6: Learning as a transform of the students’ attributes](image)

Though this model is clear it is hard to make it operational for designing education. Three questions come up immediately:

- How do we describe the input, i.e.: what are the features of the student prior to the learning process (course, module)?
- How do we describe the output, i.e.: what are the features of the student after the learning process (course, module)?
- How do we describe the learning process?
All three questions are relevant for an institute of education. Though in this phase of the discussion these questions are still open, we may observe some interesting and attractive properties of this approach. First input and output features are analogous: it concerns issues like knowledge, skills, understanding etc. Secondly, we may break up the process in constituent processes. An important example is the reform of a traditional engineering curriculum into a Bachelor-Master-structure. We will discuss this in somewhat more detail.

The Bachelor-Master structure as it has been agreed in the Bologna declaration is a typical example of the ‘cascading’ of educational programmes, as is shown in Figure 7. In this figure it is illustrated that Bachelors from one university might enter a masters programme of another university and that external Bachelors may enter into a different Master-programme.

![Fig. 7: Connection between Masters and Bachelors programmes](image)

The key problem is the connection between the two programmes, or, in other words: the (mis)match between the features of the Bachelor, graduated in one university and the expected features for a Bachelor to enter the other university; this will be discussed in more detail.

2.3. Input versus output description of education

For a further discussion of the problem of matching Bachelor and Master-programmes we refer to Figure 8, which can be considered as an alternative version of Figure 6.

![Fig. 8: The student as a “learning process”](image)

In this diagram it is assumed that the student transforms the offered teaching into knowledge, skills and understanding. As mentioned previously, this depicts clearly the traditional views on education. When a teacher is asked to describe his module, he will start to give the name of the module. Consequently, the contents will be described on the basis of the material used (books, lecture notes). Similarly, a curriculum is described on the basis of a number of modules. In fact, this is a description of the input of the process as depicted in Figure 8. We only know something about the output, if we know what the student has done with the education offered. The information on the output is
based on an assumptions of the student behaviour and a, usually rather poor, verification. This can be illustrated with a well-known remark “They should know this, because they have followed the course on xxx.” In this remark a statement is made on the output of the process (“They should know this”) on the basis of knowledge of the input (“they have followed the course on xxx”) and an assumption of the learning process. Obviously, this approach will lead to problems if educational processes are cascaded as was mentioned in the BSc-MSc example. As a consequence, we should focus on the output of the process, which implies a description of the features of the student after having been subjected to the educational process. This leads to what is nowadays referred to as output oriented education (Figure 9) (e.g. Heitmann, 2003)

As an example, in Figure 10 the relation between input and output oriented education is depicted for an example taken from electrical engineering.

Output description may seem something new and fashionable. However, due to internationalisation this approach is becoming more and more important. Two important aspects are:

- internationalisation of education:
students, who, after having acquired a BSc-degree, want to ‘migrate’ from one university to another, need a clear understanding of the required qualifications for further study. Similarly, universities offering Master-programmes have a need for detailed information on the knowledge and skills of incoming students.

- internationalisation of the labour market:
  graduates from universities all over Europe may enter the European labour market. Therefore, also employers need to know what the qualifications of graduates exactly are.

A preliminary conclusion from this discussion is that, if we design education, the emphasis should be on the envisaged output features of the graduates.

3. Feedback structures
So far we have described the educational processes as strictly ‘feed forward’ processes. This implies, that we haven’t yet included any method of verifying whether the objectives (the envisaged learning outcomes) are indeed realized. In engineering terms: the system lacks feedback.
Returning to Figure 5 we define the input of the educational process as the envisaged features of the graduate and the output as the actually realized features. This process is suitable for including feedback since both input and output are of the same nature (i.e. features). In terms of control engineering the input is the ‘set point’ (‘reference value’) and the output the ‘controlled variable’. In order to introduce feedback we need measurements. In education this implies e.g. examinations etc., or, more generally formulated: assessment (Figure 11).

![Fig. 11: Assessment of education: measurements](image)

If the result of the assessment isn’t satisfying, it is usually assumed that the students didn’t acquire the envisaged features. However, this conclusion may be questionable. Very often the assessment doesn’t really verify whether the teaching objectives are met. Students are often very smart in solving problems without a good understanding of the underlying theory. Also, it may be that the teaching objectives are not realistic. We may try to teach a blind person to read, but he will fail in any test! Finally, the teaching and learning environment may be poor: poor lectures, bad books, inadequate laboratories etc. Therefore, if we want to extend the educational process to a controlled process, we need to include different feedback paths. In Figure 12 these paths are depicted.
The feedback pathways are:
I: adjustment of assessment method
II: adjustment of students’ activities
III: adjustment of teachers’ activities
IV: adjustment of envisaged features

As in technical systems we have to take care of issues like time constants, gain factors and signal-to-noise ratios of the individual control loops.

It can be concluded that assessment plays a key role in educational systems, not only for the students but also for the management of education (Rompelman, 2000).

4. Design methodology
It is well known that the successful design of technical systems requires a highly structured approach. This approach is usually referred to as a methodology. One of the key features of such a methodology is the distinction of well-defined and usually successive phases. As an example we refer to the seven-phase model of the integrated life cycle of technical systems as it has been used for nearly ten years in the end BSc-project in the TU Delft Electrical Engineering program (figure 13).
A. Investigating the need of a product. What is the underlying problem? What is the context? Why is it a problem?

B. Specifying requirements and reflection on ‘What do we want?’ rather than ‘How do we want it?’; resulting in the Product Requirements Plan” (PRP)

C. Designing. Develop different concept systems, evaluate the concept systems with reference to the, leading to the Product Requirements Plan” (PRP) and choose the most promising concept system.

D. Developing the Product Design: prototype; verification with respect to PRP

E. Production and putting the product into use.

F. Use, management (including quality) and maintenance of the product.

G. Liquidation, (partly) disassembling and renovation of the product.

Roughly spoken, phases A – C are mainly preparation phases (the actual ‘design’) whereas the construction is just one mere phase in the life cycle. As can be seen from the figure the phases D, E F and G have an important influence on the design phase. In practice, this means that the designer has to contemplate on all these issues when designing a system. In practice, this means that he has to think about the future: he should try and formulate (a) questions like “can it be implemented and how?” “can it be used and how”, “can we verify whether the systems does what it should do and how can we verify this?” “what are the costs involved?” “what is the environmental impact?”, “how long should the system be in operation (life cycle) and what do we do after its life cycle has come to an end?”. All these considerations will contribute to a set of design criteria; this set is referred to as the “Product Requirements Plan” (PRP), which is the result of phase B in Figure 13 (ten Haaf, Bikker & Adriaanse). In fact, the requirements imposed by the reflection on ‘the future’ lead to a set of boundary conditions in the PRP. The main item in the PRP is a clear description of what the system is supposed “to do”, i.e.: what we envisage to arrive at when using the product. This latter is often referred to as the principal function of the system. It may be clear that the PRP plays a key role in the design process since it largely determines the operation of the system once realized.

As can be seen from the figure the subsequent phases are not unidirectionally related. This reflects the dynamics of the entire process in which it is allowed (and, even more, advisable) that in the process we may return to a previous phase if we discover that assumptions in a previous phase appear to be erroneous.

5. Consequences for designing educational systems

In the previous sections we have discussed the systems approach to (engineering) education as well as a general framework for design. In section a basic framework for curriculum design is discussed. The phases as depicted in section 4 (Figure 13) can be made appropriate for the educational setting. This leads to the following characterisation of the phases:
A. Investigating the need of a product.
What is the educational problem? Why are we not satisfied with the present situation? Is there a change in the demands from the market? Is there a problem with follow-up studies?

B. Specifying requirements.
What knowledge, skills, competencies should the student acquire and why? This should in some way be related to the output specifications of the entire program. Formulate a Product Requirements Plan” (PRP). (To be discussed in more detailed later).

C. Designing
Formulate different concept solutions to the problem. Evaluate the different concepts and choose the best one on the basis of the PRP

D/E Production (usually there is no distinct prototyping since it is a matter of just one realisation)

F Use, management and maintenance.
This relates to the course practice, including the quality management. In this phase the assessment structures as discussed in section 3 are to become operational

G. Liquidation, (partly) disassembling and renovation of the product.
These issues seem to be of less relevance. However, just as is the case with technical systems also educational systems are subject to wear and obsolescence. In this phase we may modify the system or replace it by another one. In the latter case, part may be used in a new system (usable lecture notes, courses, laboratories).

As in the design of technical systems the PRP plays a dominant role in the life cycle. The issues mentioned are to be taken into account. Obviously, a PRP should be structured in a conveniently arranged way. This leads to the following possible structure.

1: Definition of the educational problem (result of phase A.)
2: A clear description of the envisaged knowledge, skills competencies of the students ‘after having been subjected’ to the education. This description should be output based as discussed in section 2.3. Obviously, the description of the envisaged outcomes should meet a number of criteria:
   • they should be realistic given the attributes of the target group (prior knowledge, skills) and the time available for the students (credit points!)
   • the outcomes should be testable; if not, they should be left out or reformulated.

3: Boundary conditions
A number of aspects have to be taken into account and elaborated into (again) requirements, such as:
   • The envisaged lifetime of the module
   • The development of the system (usually staff time) (Phase D/E)
   • The assessment structures (see also Figure 12) (Phase F)
The staff needed (Phase F)
The infrastructure needed (rooms, laboratories, computers) (Phase F)
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The function of the PRP is threefold:
1. it provides the framework for designing an educational system
2. it is a frame of reference to test different concept solutions (concept systems) in 
   order to find the most promising solution
3. it is a framework for verifying the resultant educational system.

This latter issue has to be related to the assessment structure as discussed in Section 3.
As is often the case in education (but also in technical systems) in the course of the 
application of the system, the expectations may change. Teachers of follow up courses 
may have a different view on the outcomes. In particular this is a problem with input 
oriented modules! Also the original environmental conditions may change: less money, 
less staff, changing attributes of incoming students etc. In that case the PRP is a useful 
frame of reference that is extremely useful for keeping possible discussions sound and 
to the point.

6. Conclusions
The introduction of the Bachelor-Master structure and the internationalisation of 
engineering education have made it inevitable to reflect on our educational processes. 
Goals have to be redefined and programmes and curricula have to be adopted or even 
restructured. The application of the paradigms of systems theory, including feedback, 
may enlighten and structure the processes involved. The engineering sciences have 
developed powerful tools for a systematic approach to the design process. These tools, 
combined with the logical application of the systems approach, appear to be highly 
valuable in curriculum development.

References
Constructivist Perspective, Prentice Hall

G. Heitmann (2003), Innovative Curricula in Engineering Education, E4 Thematic 
Network: Enhancing Engineering Education in Europe, Volume C, Firenze University 
Press

ingineering education and the consequences for assessment”, European Journal of 
Engineering Education, 25, 339-350

and Management, Delft University Press