Performance-Based Curriculum Design

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Abstract
Too many faculty members approach curriculum revision or design from the standpoint of their own course. The question:"Where does my course fit in the new curriculum?" is heard too often. One of the primary difficulties when revising a curriculum is to focus first on the curriculum as a whole (the cathedral) instead of the bricks (courses) from which it is made.

This paper presents a methodology to focus initial curriculum revision attention on the whole curriculum and the desired performance capabilities of its graduates instead of on its component parts. This methodology has been used successfully at the Delft University of Technology in the design of its Offshore Engineering MSc curriculum as well as its new Civil Engineering BSc curriculum.

The methodology results first in a graphical representation of the curriculum in which a typical graduate's intellectual development level (for knowledge and for skill) is indicated along vertical axes for each step along the horizontal life-cycle of a typical engineered object. This life-cycle extends from problem definition in step 1 through detailed design and ends with removal and recycling of the object at the end of its economic or useful life in step 12 along that line. The result is a one-page graphical curriculum profile.

The succeeding steps by which this profile has been transformed into a working curriculum (made up of courses) are outlined. A few of the resulting innovations and surprises are indicated as well.

Introduction
The curriculum profiling methodology being presented here was first used in a very primitive way by Vugts (1994)[1] when first mapping out a curriculum for Offshore Technology at the Delft University of Technology. Later, this was refined by Vugts et al (2001)[2] when re-designing the Delft Civil Engineering curriculum from a single 5-year engineering degree to two-phase BSc-MSc curriculum structure. It has since been further developed by Massie (2002)[3]. The methodology can be applied to most any engineeing curriculum which involves design in some way.

Most recently, Massie (2003b)[5] has become involved as well with the so-called Body of Knowledge (BoK) discussion within the American Society of Civil Engineers. The profiling methodology presented in this paper can be used in this context to further specify (relative to the BoK requirements) a curriculum's technical content.

Relation to ASCE Body of Knowledge
The primary focus within curriculum profiling is on the (technology-based) tasks which (Civil) Engineers perform and the intellectual level to which a curriculum prepares its graduates to perform these tasks. In contrast to the apparent ASCE BoK requirements Anon. (2002)[6], Massie (2003a)[4], profile development originates from technical capabilities; all necessary additional abilities needed to carry these out are included implicitly rather than explicitly. Indeed, experience in Delft has been that many of the other BoK items are included inherently in the resulting curriculum.

Profiling Basics
The life-cycle of an engineered object forms the primary horizontal axis. Two parallel vertical axes - for knowledge and for skill - are used to show the desired intellectual development levels to associate with each of the horizontal life-cycle steps. A third horizontal dimension can include each specialization whenever wide differentiations are present in a curriculum. Only two dimensions have been needed for the Delft Civil Engineering curriculum however; its BSc curriculum is quite homogeneous and it is implicitly understood that the MSc part of the profile applies only to the chosen specialty. Only two dimensions will be used here as well.

<u>The Horizontal Axis: An Object's Life-Cycle</u>
The profile's main horizontal axis is based upon 12 steps of an engineered object's life-cycle:

1. **Define** - with the client - **what is needed.** This involves both communcation with the client to determine the 'root' of the problem as technical insight about alternative solutions.
2. **Determine** its **design** or performance **criteria**. Client communications as well as familiarity with design codes, for example, is essential here.
3. **Create** conceptual **solution alternatives**.
4. **Evaluate and select** - with the client - the best alternatives from among these **concepts**.
5. **Subdivide** the selected concept to yield a number of schematized and related sub-problems to be solved. These will often be both technical and non-technical in a civil engineer's context.
6. **Solve** the sub-problems individually.
7. **Combine** and **synthesize** these sub-problem solutions.
8. **Evaluate** remaining alternatives - often using more than just technical criteria - and **rank** results.
9. **Select** - again with the client - the best choices and fix the design.
10. **Supervise** construction or **realization**. This can involve such diverse aptitudes as project planning and control, labor relations and client interaction as well as being able to alleviate or circumvent immediate technical difficulties that may arrise.
11. **Supervise** and monitor **use** and lifetime condition. Interaction with users is important here.
12. **Remove and recycle**.

Most will recognize that steps 5 through 7 in this list form the heart of the curriculum's technical content.

The Vertical Scale: Intellectual Development Level

Each vertical axis uses a scale including the following five general intellectual development levels:

1. **Undeveloped**. This is a zero-level corresponding to that of an entering BSc freshman.
2. **Awareness**. One can recognize a problem and present it to one who is more expert even though one cannot solve the problem alone.
3. **Routine**. At this level one can solve commonly-occurring problems using well-known, standard procedures. (This is typically the graduation level of many engineering technologists - at least in Europe.) In addition, a university graduate can explain the procedure used and its background to others.
4. **Advanced**. One can handle more difficult problems - for which one must find or develop and document a somewhat original solution or methodology. Additionally, He or she can evaluate the relative merits of various alternative solutions that have been found.
5. **Superior**. One can now work with new and more complex problems (often only within one's specialty area) and develop, evaluate and document solutions for them. This is the highest level attainable from a university experience alone.

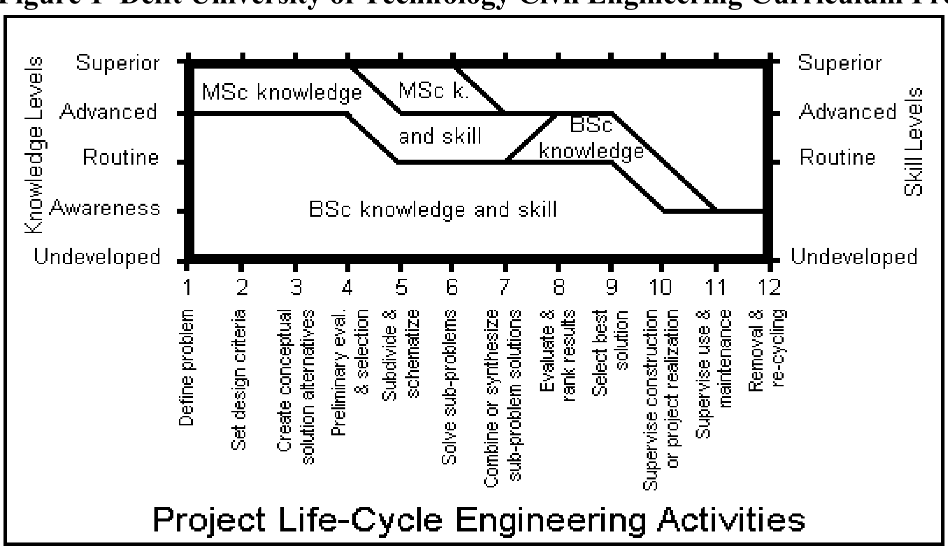
Knowledge and Skill

Two somewhat related and parallel vertical axes have been used to indicate intellectual development: One referrs to **knowledge** and the other to **skill**. (**Knowledge** here describes what a graduate knows. **Skill** is his or her handiness and effectiveness in utilizing that knowledge. Since skill follows from knowledge in this definition, a person's skill level can never exceed his or her knowledge level.) A skill level can be associated with each intellectual development level except level 2; skill is difficult to associate with awareness.

Resulting Profile

The above profile has been developed for the new civil engineering BSc curriculum as well as (genericly) for each of its MSc curricula at the Delft University of Technology. This is shown in figure 1. Note that at the BSc level, the profile includes all the civil engineering specialties included in the curriculum; the MSc portion of the profile applies only to the specialty chosen.

Figure 1 Delft University of Technology Civil Engineering Curriculum Proflile



In a somewhat abstract sense, the rectangle represented by the profile axes in figure 1 defines all of the knowledge and skills which a university can give an engineering graduate. The significance of this will become apparent below.

Profile Uses

Defining a curriculum profile is an important first step in performance-based curriculum design. Indeed, it serves several purposes:

1. It focuses attention on what a faculty wants its curriculum to achieve instead of on the courses needed to accomplish this.
2. The profile is a simple image explaining to everyone - faculty as well as students or industry - just what the curriculum is out to achieve. Just as important, perhaps, it also documents what the curriculum makes no attempt to achieve, either. This is the open section of the rectangle - the upper right in figure 1 in this case.
3. It serves as an excellent first step in curriculum design as will become obvious below.

Further Curriculum Design Steps

The Delft BSc curriculum was treated as an engineered object during the curriculum design process. The curriculum team simply adapted the 12 horizontal axis steps used in the profile to carry out the curriculum development.

1. **Define the problem and what is needed.** The faculty needed a three-year BSc curriculum which could be followed by any one of the several 2-year MSc specializations. (This 3-2 split was dictated by the Minstry of Education as a result of a European agreement, by the way.)
2. **Determine its design criteria.** What specifically must graduates be able to do once they have their BSc or MSc diploma? The answer to this was conveyed in the above profile. An additional curriculum design requirement was that the Freshman year should convey a realistic impression of the profession being entered.
3. **Create conceptual solution alternatives**. A completely general and homogeneous (civil engineering) BSc curriculum was considered on the one hand, as was a collection of several parallel BSc curricula with each one including a significant specialization at the cost of breadth.
4. **Evaluate alternatives and select the best**. Delft chose to keep its civil engineering BSc curriculum general and broad; it was to expose all students to all areas of civil engineering which it includes. The resulting curriculum structure was much like that for civil engineering at Georgia Tech; it was quite different from what one finds at Texas A&M or Worcester Polytechnic Institute. It was implicitly understood as well that the MSc part of the profile would apply to whatever specialty happened to be chosen.
5. **Subdivide and schematize the problem to form a number of sub-problems**. A curriculum can be divided into a few (about 10) blocks of activities such as basic sciences, structural engineering, team projects, etc. Each of these blocks encompasses the entire treatment of the topic within the chosen curriculum; each block usually represents a lot more than one (traditional) course taught in one semester.
   Even though these blocks did not correspond to the life-cycle steps above, the intellectual development levels were still used to indicate the level of curriculum development needed. In the Delft civil engineering case, the largest of these blocks was structural engineering. It represented roughly three quarters of a year (equivalent) of student effort over a period of

three years. It combined topics including technical drawing, materials science, statics, strength of materials, structural analysis and design of steel, concrete and wood structures. The smallest curriculum block was for introducing civil engineering to the new Freshmen; it envisioned only two weeks of concentrated student effort at the very beginning of their first year.

6. **Solve the sub-problems**. The curriculum revision team worked out only one or two of these blocks itself. Each of the remaining blocks was assigned to a respected faculty member from the chosen field. He was given a good indication of what was wanted in terms of general topic area and level of development in addition to the total curriculum space available to him. He was asked to suggest a specific content for the block that would be acceptable to him and his colleagues. His job was to provide the intellectual support for the desired development level in his field.
   This part of the process went remarkably smoothly - possibly because no discussion of specific courses had been needed yet. The level of treatment within each block was continually checked against the specified intellectual development level. Material that was above the BSc level was reserved for the MSc curriculum.
7. **Combine and synthesize sub-problem solutions**. Fit the resulting curriculum blocks together in a logical way. This obviously requires subdividing the above blocks into individual courses in order to structure the material for scheduling, study and evaluation. The desire to make the Freshman year more representative of the profession led to delaying some of the mathematics to as late as the third year - when it could be taught much nearer to its application area courses.
8. **Evaluate and rank results**. Invariably a number of smaller-scale questions must still be resolved. One question in the Delft case involved when to include runoff hydrology. Should this be placed toward the beginning or the end of the BSc curriculum?
9. **Select best choices**. Here is where the last major curriculum decisions were made. The design team moved hydrology to the Freshman year in Delft to make the year more representative of the profession. The final decision on the curriculum was made by our Dean of Civil Engineering in the Fall of 2001; the curriculum was ready for further implementation.
10. **Supervise realization**. The faculty gave itself almost a full academic year in which to prepare to launch the new curriculum in September of 2002. Course documentation and many other preparations for teaching the new curriculum took place during the year. Leadership for this was given to the faculty curriculum director; he had not been a member of the curriculum design team by the way.
11. **Supervise use**. The curriculum (in addition to the individual courses in it) should be evaluated periodically so that it may be fine-tuned. This process is just starting for most curricula in Delft. Improvement suggestions based upon fresh experiences have been actively sollicited from both staff and students in the offshore engineering MSc curriculum for several years, however.
12. **Removal and recycling.** It is certainly too early for this. Indeed, if step 11 is carried out properly, it may never be needed; see Massie (2003a)[4].

A Look Back

Note that all of steps 1 through 6 were carried out before specific courses entered the discussion. Indeed, individual courses are simply a necessary evil of having a curriculum. Their only purpose is to facilitate student performance monitoring and curriculum administration.

It was discovered in step 7 that some of the individual courses could best be taught by a team of teachers - each contributing his own expertise - instead of by a single instructor from a single specialty area. Implementation has been made more difficult by fears that the administration will not be able to cope with this.

One particular innovative suggestion was that the Introduction to Civil Engineering course be taught on a full-time basis during the first two weeks of the Freshman year. This would help each new Freshman confirm that his or her curriculum (and later professional) choice were correct early in their academic career. (This has worked successfully at several other Dutch universities, by the way.) Unfortunately, the adminstration involved with the required special scheduling of other courses in the semester apparently prevented the implementation of this idea in Delft.

The curriculum design team made an extraordinary effort to maintain widespread and open, two-way communications. For example, the task for each expert in step 6 was published on the web. His response appeared there a few weeks later, too. Throughout the entire process, the team chairman scheduled a noontime office hour for unscheduled short discussions or to make a longer appointment.

Conclusions

Profiling defines the technical content of a curriculum in more detail than does the ASCE Body of Knowledge. This is quite logical; a profile describes a single curriculum. The BoK must be more universal; this forces it to be more abstract. The profile does complement the BoK and may ultimately become more strongly linked to it.

Making the profile keeps attention - for quite some time - focussed on the curriculum as a whole rather than the courses which make it up. The result is handy when explaining just what the curriculum stands for. Anyone can understand the profile - after a short explanation.

A curriculum can be treated as an engineered object. The steps which describe an engineered objects life-cycle as well as principles of engineering design can be fruitfully applied when designing an engineering curriculum as well as any other engineered object. The reader may reflect upon why so few engineering faculty seem capable of doing this - at least so explicitly.

Courses are only a necessary evil within a curriculum. They serve to facilitate scheduling, student progress monitoring and faculty administration. Try, therefore, to prevent existing courses and rigid administrative rules from getting in the way of educational innovation.

Continual and open communication is a key to successful and trusted curriculum reform.

References

Note: All references are in English unless otherwise noted.

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Biographical Information

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Walt has a primarily US background in Civil as well as Mechanical Engineering. He first went to The Netherlands as a Fulbright Scholar in 1968 and has been on the faculty of the Delft University of Technology since 1970. He has filled various functions within the Faculty of Civil Engineering and is currently the Interfaculty Offshore Engineering MSc Curriculum Leader.