Justifying a Body of Knowledge

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Abstract

There has recently been a lot of discussion going on within the membership of the American Society of Civil Engineers (ASCE) about credentials for professional practice. The American Society of Mechanical Engineers (ASME) is now starting its own discussion on this same topic. At the same time, few, it seems, have attempted to objectively justify a Body of Knowledge (BoK) - a modern term for such credentials.

The underlying premise of the paper is that most engineers work somewhere along the life-cycle of an engineered object. This life cycle was used to design a new Civil Engineering curriculum for the Delft University of Technology in the summer of 2001. The result was a definition - for each step in the life-cycle - of the knowledge and skill levels to be provided by the Delft civil engineering BSc and MSc curricula.

This paper continues further - still using the life-cycle - now to define the aptitudes (the result of knowledge and skill) needed to optimally perform engineering activities associated with each life-cycle step. This now results in a matrix associating aptitudes with each life-cycle step. Such a matrix is easy to understand and explain; it serves as a very graphic justification for these aptitudes.

The resulting list of aptitudes is compared to the ASCE BoK at the end of the paper.

Introduction

The quality of engineering education in relation to the needs of practicing engineers has been a topic of discussion for more than a quarter century within the profession. In the mid-seventies the ASEE Goals of Engineering Education report suggested that a five-year curriculum be required to support a "first professional degree". The focus at that time was more on the length of the study path than on its content, however.

A fundamental flaw inherent in most university faculty is their primary focus on (their own) courses rather than on the curriculum as a whole and how that whole serves the profession. Vugts¹ broke with this tradition by primitively defining the needs of a curriculum in terms of desired performance rather than courses. Indeed, courses - as such - were not even mentioned in
ASCE and its Task Committee on Academic Prerequisites for Professional Practice has taken a somewhat different - more content-oriented - path by extending the ABET requirements to come to what they call a Body of Knowledge (BoK). That team has gathered and processed a wealth of information to come to an admirable (draft) document in the fall of 2003. A possible shortcoming of the document is its failure to link its BoK items more closely to professional practice. This is achieved in this paper by linking aptitudes to steps in the life-cycle of engineered objects and thus to the professional activities at each step.

Curriculum Profile Review

A profile is a two-dimensional graphical representation of the overall objectives of an engineering curriculum - without regard to the courses that are used to meet those objectives.

Horizontal Axis and Scale
The primary (horizontal) axis is a succession of twelve steps describing the life-cycle of an engineered object or system from problem (or need) definition on the left to removal and recycling on the right as defined below:

1. **Define** - with the client - the underlying problem to be solved.
2. **Determine** its design or performance criteria.
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 non-technical as well as technical.
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**.
11. **Supervise** and monitor **use** and lifetime condition.
12. **Remove and recycle**.

Most will recognize steps 5 through 7 in this list as the ones that are at the heart of an engineering curriculum’s technical content.

Vertical Axes and Scale
Two parallel vertical axes are used in a profile: One for knowledge and one for skill. Skill is defined here as one's handiness at using knowledge. By definition, thus, one's skill level cannot exceed his or her knowledge level. The axes for knowledge and skill have essentially identical intellectual development scales:
1. **Undeveloped**: This is commonly associated - in this context - with a freshman entering the university.

2. **Awareness**: One can recognize and discuss a problem, but he or she cannot solve it.

3. **Routine**: One can apply well-known standard solutions to standard problems. In academic terms, this is typically associated with a graduate having a technology rather than an engineering degree.

4. **Advanced**: One is now able to solve at least some less conventional problems. It is typically the highest level associated with a Bachelor of Science degree.

5. **Superior**: Now one can break into new by developing new or improving existing methodologies in one's specialty. It is typically the highest level associated with a Master of Science degree.

6. **Mastery**: This is the highest attainable level; it that is higher than is attainable via university study alone. One becomes a respected expert in one's field only after some years of experience.

**Resulting Profile**

Profiling methodology has been used to define the goals for both the new BSc and MSc Civil Engineering curricula as well as the Offshore Engineering MSc curriculum at the Delft University of Technology. The resulting Civil Engineering profile in figure 1 is typical.

Perhaps surprisingly, once the profile had been defined, it proved to be rather easy at the time to achieve consensus on what should be taught within each of the Delft Civil Engineering curricula. On the other hand, the ever-evolving ABET criteria justify a review.

![Typical Curriculum Profile](image-url)
Aptitudes Needed for Various Life-Cycle Steps

The life-cycle has been used as a basis to review the knowledge and skills needed by typical engineers involved with that particular life-cycle step. The most important of these aptitudes are highlighted in the following list in which the activities associated with each life-cycle step are discussed.

1. **Define** - with the client - **the underlying problem** to be solved.
   This involves communication with the client as well as a bit of psychology, perhaps, to get to the root of the problem. The engineer must - at this stage - be wary of the client who arrives with request only to design a specific (given) alternative solution. Instead, one should first dig deeper with the client to determine the underlying problem to be solved. Proper definition of the overall problem makes it possible to take a broader view in later life-cycle steps so that there is a greater chance of selecting (and selling) an optimum solution to that underlying problem.
   On a larger project, one will probably have a multi-background team representing the client in this stage; this can make this life-cycle stage more challenging. This will - in turn - motivate a need to be able to work in and lead a multi-disciplinary team. An impeccable professional reputation will be an asset at this point too.

2. **Determine** its **design** or performance **criteria**.
   An engineer working on this step will need to be familiar with typical system performance requirements and be able to communicate well with the client in order to define the new system's specific performance criteria. Later work will be more satisfying - for all parties - if these criteria are reasonably realistic. Safety in an absolute sense is really impossible to achieve, for example. The criteria defined here should include all relevant facets: Employment of locals is a valid criterion just as is cost or technical feasibility. Multi-background teamwork as well as leadership and a bit of salesmanship will all be needed in this step, too.

3. **Create** conceptual **solution alternatives**.
   This is where creativity and a brainstorming ability are essential. One who thinks too conservatively is at a disadvantage during this life-cycle step. The focus here must be positive - on what can or might be done to solve the problem (at a conceptual level) rather than on the problems which must be overcome with any given solution concept; these will come up in the next step.
   Working within a multi-background team can increase productivity and the chance of finding more and more innovative concepts in this project stage.

4. **Evaluate and select** - with the client - the best alternatives from among the **concepts**.
   The results from steps 2 and 3 should be combined here and evaluated by a broadly-based team including the clients, their advisers and of course engineers and contractors as well. Good communication along with a healthy dose of leadership is essential here. The engineer leading this process will have to know the various design criteria and be conversant with and understanding of the various viewpoints represented by team participants. The broad perspective developed in step 1 can make this evaluation more balanced, at least. Conflicts of interest can emerge during this step; a high level of impartial professionalism is required here, too.
In some cases it may be necessary to continue discussion until a single solution concept has been selected; in some other cases it may be possible keep a few different solution concepts alive pending a more detailed evaluation in step 8.

5. **Subdivide** the selected concept to yield a number of schematized and related sub-problems to be solved.

   Obviously, most any civil engineering project will involve both technical and non-technical sub-problems to solve. Even so, the communications circle is now becoming smaller and more specialized; one is working more with a team of specialists, now; the public is not really involved at this stage.

   It is an art - as engineer - to be able to break down a large and complex problem into a number of related sub-problems to be solved for later synthesis. This requires good analysis skills as well as a global view of the possibilities offered by, and limitations of, each of the specialties (potentially) involved; knowledge breadth rather than depth is required at this step along the life-cycle. It is important, as well, to convey the proper context of each sub-problem as it is prepared for a specialist; this improves the chance that the sub-problem solution will indeed fit into its proper place in the whole.

6. **Solve** the sub-problems individually.

   In a large project, the myriad of sub-problems will be solved by nearly as large a group of experts - each concentrating creatively on his or her particular sub-problem. It is obvious that they will need specialized analysis and design expertise here, and may even have to develop new knowledge via modern library use or even via the design and execution of experiments. People working on this life-cycle step will have the design team - and possibly colleagues working on adjacent puzzle elements - as colleagues. Their communications are with a very specific group instead of the general public. Of course each of these specialists can - in turn - treat his or her specific sub-problem as an entire project with its own, more refined, life-cycle steps.

7. **Combine and synthesize** these sub-problem solutions.

   The quality of the work done in steps 5 and 6 becomes obvious here! If the subdivision or the sub-problem's context has not been clear, then one is rather lucky if the resulting pieces of the solution fit together properly. Those on the design team who are fitting things together will need a significant knowledge of what is behind each sub-problem solution in order to make the necessary interpretations in a responsible, professional way. They will have to depend upon communications from those who carried out the myriad of activities in step 6 to forge and synthesize workable solutions from all of the pieces provided.

8. **Evaluate** remaining alternatives - often using more than just technical criteria - and **rank** results.

   This is where a design team widens its communications circle again to include non-specialists. While much of the evaluation can be done within a balanced design team, it will probably need additional supporting expertise - and leadership from within the team - in order to make a meaningful evaluation based upon so many very distinct criteria as have been formulated in step 2. Once again, a high level of professionalism and impartiality is needed in the design team leader.

9. **Select** - again with the client - the best choices and fix the design.

   The client - and often the general public as well - obviously plays an important role here. Still, it is the task of the engineer leading the design team to help them make an intelligent
and well-founded decision. A broad knowledge and leadership as well as salesmanship aptitudes are needed here along with the ability to work with such a diverse group of persons. The project must be viewed from a wide variety of technical as well as non-technical perspectives in order to make a well-founded selection.

10. **Supervise** construction or **realization**.
Those supervising construction must work within a new communications circle. They obviously interface with the client and the design team, but they are also faced with the general public (in the possible form of a protest group) on the one side and the construction workers (and their unions) on the other. A good negotiator and salesman can be invaluable here. One's technical background is most used to solve the myriad of individually small problems that appear to have been overlooked earlier or may simply result from a contractor's construction methodology. More comprehensive - and hopefully less pressing matters - are deferred to the design team for solution. Since most of a project's direct costs are incurred in this phase, a good bit of labor and financial management is essential to success.

11. **Supervise** and monitor **use** and lifetime condition.
Interaction with users is important here, just as it is with the myriad of staff and (contractor) disciplines that keep the facility functioning optimally. Labor and financial management remain essential.

12. **Remove and recycle**.
A supervisor has a personnel task similar to that of the supervisor in step 11. He or she forms the interface between the public, the owners, and the demolition contractor. As in many such diverse teams, leadership and salesmanship combined with professionalism are essential.

One additional item, so inherent in any profession that it should be obvious, is that every professional must continue to learn during his or her professional lifetime in order to remain up-to-date with developments in his or her field. This item is somewhat important for all of the steps mentioned above - with a bit more accent for this in steps 6 and 9.

**Resulting Matrix**

The above life-cycle discussion incorporates the high points of a body of knowledge, even if it is not immediately obvious. With a bit of interpretation and condensation of similar ideas, all of this can be transformed into a quite simple list of 21 aptitudes on one side of a matrix with the life-cycle steps orthogonal to this across the top. The cell at the intersection of any row and column indicates the importance of the link using a somewhat subjective four-level scale as indicated in figure 2.

Note that most aptitude items have an important link (darkest cell shading) to at least one life-cycle step. Those that lack this, such as item a, broad engineering knowledge and skill, are quite general and are linked to several life-cycle steps; these aptitudes are rather universally needed to some extent.
Comparison With the ASCE Body of Knowledge

How well does the above list of aptitudes compare to ASCE’s Body of Knowledge (BoK)? After all, some feel that the 15 aptitudes listed in the BoK appear to be rather arbitrary in that they lack a specific relationship with engineering practice. Since the items in figure 2 have been linked to practice, it can be interesting to try to link the above list to that developed by ASCE.

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**Relationship Scale**
- None
- Weak
- Significant
- Important

Figure 2 Resulting Matrix Relating Aptitudes with Life-Cycle Steps
Their list - as published in their Fall 2003 Draft report\textsuperscript{6} includes:

1. "an ability to apply knowledge of \textit{mathematics, science and engineering}.
2. an ability to design and conduct \textit{experiments}, as well as \textit{analyze} and \textit{interpret} data.
3. an ability to \textit{design} a system, component or process to meet desired needs.
4. an ability to function on \textit{multi-disciplinary teams}.
5. an ability to identify, formulate and solve \textit{engineering problems}.
6. an understanding of \textit{professional and ethical responsibility}.
7. an ability to \textit{communicate} effectively.
8. the broad education necessary to understand the \textbf{impact of engineering solutions} in a global and societal context.
9. a recognition of the need for, and an ability to engage in, \textit{life-long learning}.
10. a knowledge of \textit{contemporary issues}.
11. an ability to understand the techniques, skills, and modern \textit{engineering tools} necessary for engineering practice.
12. an ability to apply knowledge in a \textit{specialized area related to civil engineering}.
13. an understanding of the elements of \textit{project management, construction, and asset management}.
14. an understanding of \textit{business and public policy administration fundamentals}.
15. an understanding of the \textit{role of the leader} and \textit{leadership principles}.

Since the 21 aptitudes listed in this paper have been obtained via an analysis of the needs of the various steps in the life-cycle of an engineered object - and thus implicitly from engineering practice, it can be revealing to attempt to link these to the BoK. Figure 3 shows a matrix of aptitudes from this paper listed vertically on the left and the ASCE BoK items across the top. Once again, the darker gray shading is used to indicate a stronger link between the two items that define each matrix cell.

Those items that correspond (almost) exactly are indicated with the darkest shading at the matrix intersection cell; this is true for nine of the items.

The list of aptitudes subdivides communications based upon one's primary audience; this is not found in the BoK. The author knows from experience that communications with various audiences can be quite different and that an aptitude with one audience does not guarantee success with another.

The 21 aptitudes include some new concepts such as salesmanship in item j or modern library and internet utilization in item l. These are not (as specifically) mentioned in the ASCE BoK. Analogously, the ASCE BoK includes public policy in item 14; this cannot be found in the author's aptitudes list at all.

Some differences result from different combinations of items. BoK item 13, construction, project and asset (facilities) management, includes two entire life-cycle steps (10 and 11), for example.
Figure 3 Link between Aptitudes and ASCE Body of Knowledge

Some of the other differences probably result primarily from differences in terminology. This emphasizes the need to define terms carefully.

Conclusions

Associating needed aptitudes with steps in an engineered object's life cycle makes them less abstract and more obvious to everyone.

Engineering curricula can use the resulting matrix in combination with their particular curriculum profile to help define the - often less technical - aptitudes that must also be conveyed via their curricula.

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A comparison of the aptitudes found via this analysis and those suggested by the ASCE Body of Knowledge shows a substantial agreement; nine of the items are essentially identical. The ASCE BoK team did their work pretty well.

The most important difference between the aptitudes found here and those listed by ASCE include:

- Communications has been subdivided in this paper based upon the observation that communications with different groups of persons (technical colleagues, the public, etc.) can require quite different skills.
- ASCE puts some emphasis on public policy. This is understandable specifically for those civil engineers who must interact with public governing bodies.
- The aptitudes in this paper specifically include salesmanship and the use of libraries and internet to gather information. A quick reader might not recognize these aptitudes when reading through the ASCE BoK list.

Universities can use the engineered object life cycle along with the matrix link to aptitudes to help define the content to be conveyed via their curriculum. Professional societies can use this same approach to convince die-hards that the 'softer' aptitudes are really important.

References

3. Vugts et al (Curriculum Revision Project Team) (2001) *Together A Step Forward*, Faculty of Civil Engineering, Delft University of Technology, Delft, The Netherlands. Note: The main report is in Dutch (original title: *Samen een stap verder*) but the profiling and goals statements are in English as Appendix 5.

Biographical Information

WALTER W. MASSIE
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 university - primarily within Civil Engineering - and is currently the Offshore Engineering MSc Degree Curriculum Leader.