THE ROLE OF MATHEMATICS AND THE CONCEPT OF MODELS IN A CDIO - APPROACH

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ABSTRACT

Since the mid eighties educational concepts based on students' work as organized in groups and based on project work with assignments from the real world have dominated Danish engineering programmes as well as many others and proved valuable in terms of preparing the students for complex working situations. The Qualification Frame terminology with emphasis on competencies pushes in the same direction. In the definition of didactical methods it is suggested that theory to a large extent be substantiated by examples from the professional field in question, and that the project work comprises a range of disciplines to appear realistic.
With changing and more varying job profiles it may be a threat that students are pushed to achieve results at the expense of the supporting theory or performing sensitivity analyses.
This first inspired me to look more closely into the students approach to and qualifications in theoretical subjects. Subsequently it appeared rewarding to set up a tool describing a systematic approach to the application of theory and performing sensitivity analyses, as a supplement to achieving results in a project, or building/ constructing something as the "I" and "O" in the CDIO terminology suggest.
Engineers are very familiar with working with models, be it physical or theoretical. Proper application of the traditional modelling concept leads the students through the same stages as physically making a product, and hence enlarging the concepts of implementing and operating.

KEYWORDS

Theory in projects, Acquiring Mathematical knowledge and skills, the European Qualification Framework (EQF), Applying a Model approach to the C-D-I-O´s

ENGINEERING PROFILES

Various engineering profiles and the implications to the span of curricula

Numerous papers and reports on the required qualifications and competencies of future engineers point out that development in technology, society and profession demand more complex and varying competencies than only few years ago [1],[2]. It is typical, however, though for the same reports that the knowledge and skills within classical topics are implied, for instance in [2]. Hence classical engineering disciplines experience a pressure, and institutions are compelled to define rigorously the profile(s) of the candidates and the didactical methods applied.

Short on definitions in Qualification Frame terminology, and learning taxonomy

Incidentally, before continuing to describe profiles, it could be useful to quote some definitions in qualification frameworks, as these reflect the present level of ambitions throughout many institutions.
In the European Qualification Framework [3] the terms knowledge-skills-competencies are adopted. A short definition is as follows:

- The term *Qualification* is used to describe professional *knowledge and skills* typically, but not necessarily solely, acquired through studies. It may be theoretical and/or practical, and will often be documented by diplomas.
- The term C*ompetence* is used to describe, whether the sum of qualifications, personal qualities, experience and attitudes enables the person to solve a given assignment.

The tripartition knowledge-skills-competencies is used to characterize the various levels within the educational system, although it is obvious that competency should be regarded a super conception to the others. Competencies are characterized as:

- *Making judgements*
- *Communication skills and cooperation*
- *Learning skills*

It should be noticed, that although there are similarities, the Qualification Frame is not equivalent to a traditional learning taxonomy, which to different degrees assumes a progression between levels.

The training at engineering educations should then be organized with the aim of preparing the student to acquire competencies by solving complex, maybe vaguely defined but realistic tasks. The engineer should be trained to delimit problems, to identify solutions, and to take into consideration many constraining aspects like sustainability, economics, social conditions, and others. Project work with a proper defined assignment is a good tool to achieve this, but may suffer from each of many contributing disciplines being suppressed.

Relating the project work to the conception of a model could be a useful tool to ensure that theory supports the solutions. At the same time the conception of a model nicely follows the main ideas in the CDIO-concept as described in [4].

Engineering profiles, continued

In [5] five profiles of an engineer are suggested:

- *The Consultant* needs to be confident with standardized methods of technical solutions and their implications to a wide range of applications.
- *The Designer* needs to comprehend the final consumer’s demands to the product and any technical aspects without necessarily making the detailed design.
- *The System Builder* needs to be an expert in a narrow field yet at the same time understand the context.
- *The Organizer* needs to combine the knowledge of others into a system or a product.
- *The Model Developer* needs to be confident with both practical applications as well as theory behind models.

More traditional profiles could be added such as:

- *The Communicator:* needs to communicate the rationale behind technical solutions to a broad audience.

- *The Salesman:* needs to know strengths and weaknesses of a product, but not necessarily the theory behind it.
- *The Producer/Entrepreneur:* needs to be familiar with many adjoining fields.

The profiles above are quoted very briefly – the qualifications required and the degree of expertise vary, but common to the profiles is the ability to adopt a systematic approach. Two tendencies for more of these profiles in relation to the application of theory are [5]:

a) It is being easier to apply computer programs, while demands to those creating them increase.
b) New technology implies improved possibilities for advanced and repeated computations, but seldom less demands to the ability by the user to judge results and methods. The challenge is to educate engineers with a proper mixture of knowledge, skills and competencies.

In continuation of this the background for the investigation as referred to in the following was partly the straightforward to design effective mathematical teaching, and partly to focus on the coherence between theory and application.

STUDENTS APPROACH TO MATHEMATICS, AND REASONS FOR FAILURE

In order to investigate the prejudice that Mathematics is difficult to comprehend for Bachelor engineering students and also to find out possible impediments to the acquisition of routines in the application of basic mathematical tools, a quantitative survey was initiated. So far results from 260 students in 5 programmes have been included. For time series of parameters (marks in Maths), a succession of 5 terms of admissions have been included. For certain parameters comparisons are made to a similar investigation for first year students in the scientific programmes at Aarhus University. A huge amount of qualitative data in the form of course evaluations are available as well, but is not taken into consideration in this context. The following parameters have been investigated:

a. Rates of passing first examination in mathematics
b. Background in terms of marks from high school
c. Correlation between marks in mathematics in high school and at university
d. Particularly failing students as representative for the total population
e. The effect of participation in optional introductory courses
f. Time elapsed since qualifying examination
g. Type of qualifying examination
h. Gender
i. Possible change over time
j. Comparison between various methods of examination (projects, oral, written)
k. Students' efforts

Only selected results that lead to conclusions will be quoted. They are presented as a mixture between results and interpretations:

a. Rates of passing vary between 73% and 83%. This figure is computed solely for students actually taking part in the examination, and it is still to settle, what influences a drop-out rate of 15 -20 % at this stage. A passing rate as quoted is not considered critical, but still result later in the studies indicate lack of ability to apply the knowledge (j)
b. This parameter is included in order to compare to populations at other comparable programmes, but so far no results are available.

c. Results are shown below (figure 1) as a typical scatter diagram, and correlation is vague. Results from the Aarhus University confirm this pattern. It is obvious that the qualifications required at university level are different from those at high school: a high mark in high school does not guarantee similar good results at university, and vice versa. It must be mentioned that other investigations, e.g. [6] arrive at opposite conclusions, which could be due to more similarity between examination methods and curricula.

d. To further investigate this, marks from high school for failing students are compared to the full population. It shows that these students on average have marks that are ½ mark lower than all students. (the Danish marking scale has 7 marks, equivalent to that of the European scale)

e. Recently an optional brush-up course was offered prior to start of studies. Results are promising, but so far blurred by mainly well motivated students taking part.

f. It was assumed that students with high school qualification fresh in mind would do better at university – however the opposite proved to be true, and the difference is almost one full mark between students starting straight from high school, and students with 2 years of experience. This emphasizes the conclusion that university studies are different, and it also suggest that maturity and attitude to studies matter.

g. As this refers specifically to the Danish educational system it is omitted here.

h. There is no significant correlation to gender.

i. It is assessed that too many parameters influence this result to make any conclusions

j. Marks obtained in written examinations are significantly lower than those in oral or in project examinations (approximately ½ mark). Results from [7] show not surprisingly that marks in written test are rather sensitive to the way papers are designed. This is to be addressed, as well as the students' training in coping with written assignments in contrast to project work.

k. Students' efforts obviously play a great role. This is recorded through evaluations, but has not been possible to measure directly.

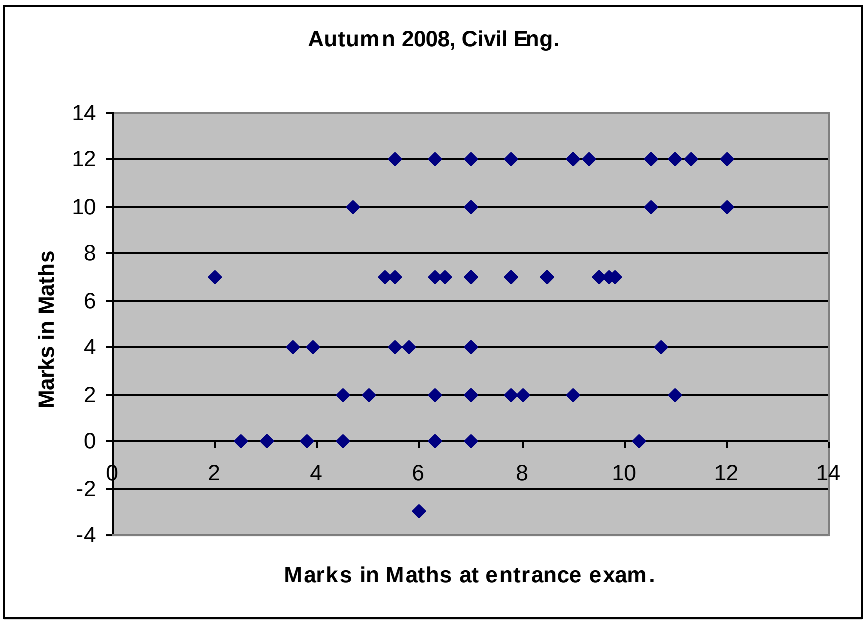

Figure 1. Scatter diagram showing the influence of marks at entrance examination

Experience shows that the interest among engineering students is directed towards application, which has lead to intense integration of application in mathematical teaching. In later subjects the importance of theory is often blurred by the use of programs or table values. Summing this up the conclusion and actions relevant in the present context were:

It should be clear when mathematical skills are trained as abstractions, and when the application is in focus. In order to motivate students, application to engineering problems is important, but only after the basic skills have been acquired. The model concept as described in [8] and [9] is considered a useful tool for this.

In project based programmes the higher levels in a learning taxonomy (application, assessment, synthesis) are often more important than skills are. As the curricula in Danish high schools recently changed to emphasize the same qualifications ("preparing for methods of studying, rather than training skills") it is important for university educations to be aware of the basic skills. This can conveniently be handled in the "Model-model"

THE MODEL CONCEPT AS FRAME FOR COMBINING APPLICATION AND THEORY

The concept of a model can conveniently be used as the framework for projects and ensuring both the application part and the theoretical part.
The principles of the model are traditional and shown in many versions. The present is inspired by [8] and is extended by the C-D-I-O stages as explained below. It is crucial that the work is circular, which means that by returning to assumptions and tools through recalculation and verification, an experience is gradually built up. In a learning environment this means building up understanding and experience of theory.

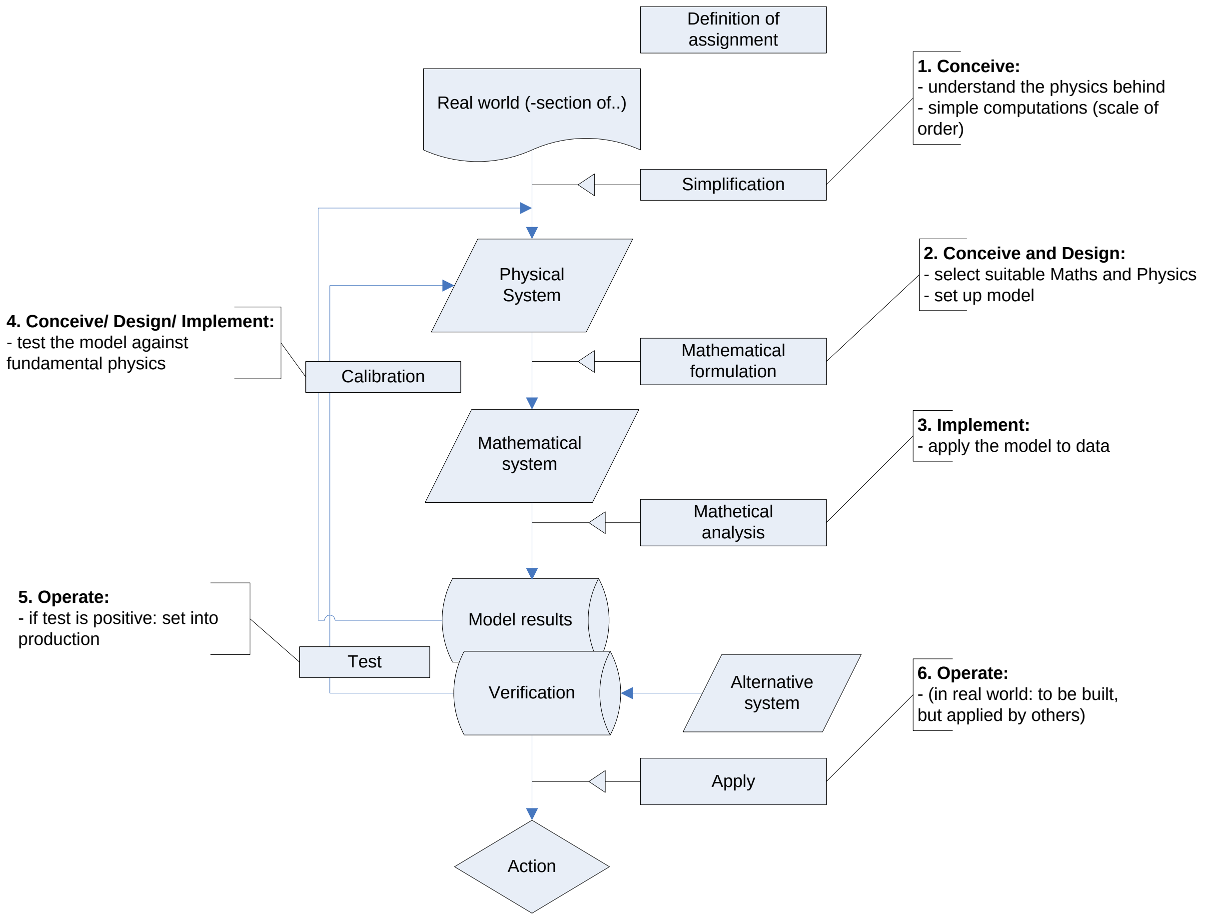

Figure 2. Stages of a model related to a CDIO-approach

The *"Conceive-stage"* (marked as "1" and "2" in Figure 2) is evident; depending on the complexity of the assignment given, it may include simplification of the real world (1), or the simplified physical system may be provided. At this stage the user needs to understand the strengths and weaknesses of Mathematics and Physics as tools in the context.
The *"Design-stage"(2)* is the process of setting up the proper formulations, be it a simple differential equation with proper boundary conditions, or be it a computer program.
The first step in the *"Implement-stage" (3)* is the work of producing results and performing sensitivity analysis. At this stage it is necessary to return to basic assumptions.
In a simplified version the concluding *"Operate-stage"(6)* would be actually constructing the physical item that was modelled. This may be beyond possible range in a university context, but advantage should be taken in the model being circular, and is suited to recalculations:
In a second and combined "Conceive-design- implement-stage"(4) test data are applied to the model – also called the a calibration. If results are valid, a final test may be performed against different data.
In model terms the model is now ready for production or the "*Operate-stage"(5)* – even though no physical items are produced.

The same sequence is illustrated by a very simple example, namely designing a beam:

Conceive:	appreciate the physics of support, loads, differential equations etc.
Design:	apply the tools to compute a beam from a real-world building
Implement:	analyze with respect to boundary conditions, price etc; re-compute as required
Operate:	compare to test results and to beams in structures; perform scale tests

REFERENCES

[1] Andersen, O. Dibbern et al, Problem Based Learning. DEL, 2002 http://www.delud.dk/dk/publikationer/PBL/index.html

[2] Stahlschmidt, J. et al, Competencies and the Mechanical Engineer (in Danish), IPN series paper no 5 (January 2006)

[3] The framework for qualifications for the European Higher Education Area (various notes from the Dublin Conference)

[4] www.cdio.org

[5] Jørgensen, U. et al, Profiles in Engineering Work and Education, IPL Institute at Danish Technical University, 2002

[6] Albæk, K., Who passes the study as Polit?, Nationaløkonomisk Tidsskrift, no. 139, p. 208-222. Printed as Blue Memo no. 204, Institute for Economy, University of Copenhagen, January 2002. (in Danish, http://www.econ.ku.dk/wpa/)

[7] Christensen, H.P. et al, An Investigation into Students Prerequisites, Learning, Understanding and Strategies for Studies (in Danish), Learning Lab. DTU, April 2005

[8] Gregersen, P. et al, Problem Solving and Modelling in General Mathematical Teaching (in Danish) Texts from IMFUFA no 353, University of Roskilde, 1998

[9] Niss, M. et al, Matematikkens verden (The World of Mathematics, in Danish), Fremad, 2001

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Jørgen Bundgaard Nielsen is Director of Studies at the Engineering College of Aarhus, and as such responsible for designing course programmes, with special emphasis on students' rate of failure, and on definition on progam levels according to the Bologna process.
He was a member of the Nat. Committee for introducing the Qualification Frame

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