INTEGRATION OF MECHANICS AND MATHEMATICS IN ENGINEERING DESIGN EDUCATION

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ABSTRACT

The bachelor curriculum of the Faculty of Industrial Design Engineering will be revised drastically from September 1st 2007, as a consequence of the introduction of a six months minor program. The Design Engineering department is in particular responsible for the engineering design subjects of the bachelor curriculum. The department will use the revision to strongly improve theoretic modelling skills of students. The method of theoretical modelling is assumed to be a base competence of scientifically educated design engineers and important for defining quantitative properties. Each engineering design course will consider the entire modelling process, i.e. will be based on the real world design situation and will include design evaluation and verification. To realize this, mathematics is an essential subject. The new engineering design curriculum will be based on the following starting-points:

- There will be no separate mechanics and mathematics courses. These disciplines will be integrated in new engineering design courses of 7.5 European credit points (210 hour).
- The mathematics topics will be fine-tuned with mechanics topics. Some mechanics subjects such as vector calculus, moment of inertia and vibration of springs will be taught by mathematics lecturers.
- To learn mechanics no artificial theoretical questions will be offered to the students, but only questions with a strong relation to design practice
- Competence oriented educational methods will be used.
- A computer system will be used to inform lecturers during the courses about the progress of individual students.

Keywords: Curriculum, engineering design, industrial design, mechanics, mathematics

1 INTRODUCTION

In September 2007 the faculty Industrial Design Engineering of the Delft University of Technology will start a complete new bachelor program for all three years at the same moment. This opportunity is grasped to greatly increase the usefulness of the engineering design subjects and in particular the more theoretical engineering subjects. The following illustrates the need for such a drastic change. In the current curriculum eight European credit points (e.c.) in total are allocated in the first year to the statics and mechanics of materials courses. Students should be able to apply the obtained basic knowledge in the succeeding courses and bridge the gap between the theoretical knowledge and the design situation. However, most students do not succeed in that. Therefore, starting from September 2007, mechanics will only be taught in a design context. This is supposed to be a required condition to learn students the application of mechanics theory in design practice. Similar considerations can be applied to mathematics, except for the direct applicability of mathematics in design. Mathematics is essential to educate bachelors of science which have more engineering knowledge than simply rules of thumb and practical knowledge. Mathematics is necessary to follow the derivations of mechanics laws and rules. In the new curriculum mathematics is assumed to serve mechanics and in a restricted way, also other theoretical disciplines. Mechanics is assumed to serve engineering design (see figure 1).

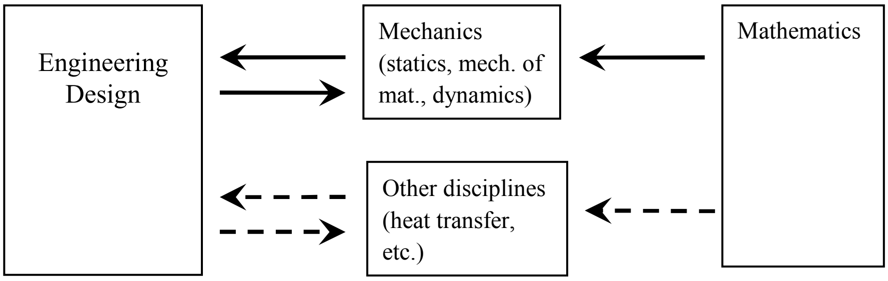

Figure 1 Mathematics tailored to mechanics and mechanics to engineering design

The introduction of a six months minor (30 e.c.) in the third year made it necessary to start the bachelor revision. Besides, it is also aimed that the bachelor revision will increase quality and success percentage. Furthermore, the third year will consist of two optional subjects (15 e.c.) and a thesis project (15 e.c.). The first two years of the bachelor will consist of 16 courses of 7.5 e.c. Each course will last ten weeks and two courses will run simultaneously. As a consequence of the freedom of choice in the third year, only the first two years will be available for mandatory courses. Unfortunately, this has resulted in a reduction of almost 50% of the total e.c. allocated to mandatory engineering design subjects. It has been chosen to reduce mathematics from 12 e.c. to 6 e.c. and electronics will almost completely disappear from the mandatory courses (currently, electronics is quite important). Conversely, statics and mechanics of materials approximately will remain unchanged. These two mechanics subjects in particular and partly dynamics will be used for teaching theoretical modelling skills

2 MECHANICS MODELING IN A PRODUCT DESIGN CONTEXT

Students often consider mechanics to be a magic box that can calculate anything. They are often not aware of the constraints and the underlying assumptions. Often the calculations are not preceded by an analysis of the real world situation, including the requirements, and hardly any attention is paid to the evaluation and validation after the calculation. Undoubtedly, the artificial theoretical questions that are offered to the students are to be blame for this. Therefore, in the new curriculum only exercises with a strong relation to design context will be offered to the students and they will be asked to model the mechanics situation in a all-embracing way. This is visualized in figure 2. Every exercise will ask the students to perform the following steps.

- Analyse the design situation and formulate the relevant requirements.

- Establish the analytical model (Free Body Diagram) and point out the assumptions and simplifications.
- Perform the calculation
- Evaluate the design proposal
- Verify the validity of the theoretical model.

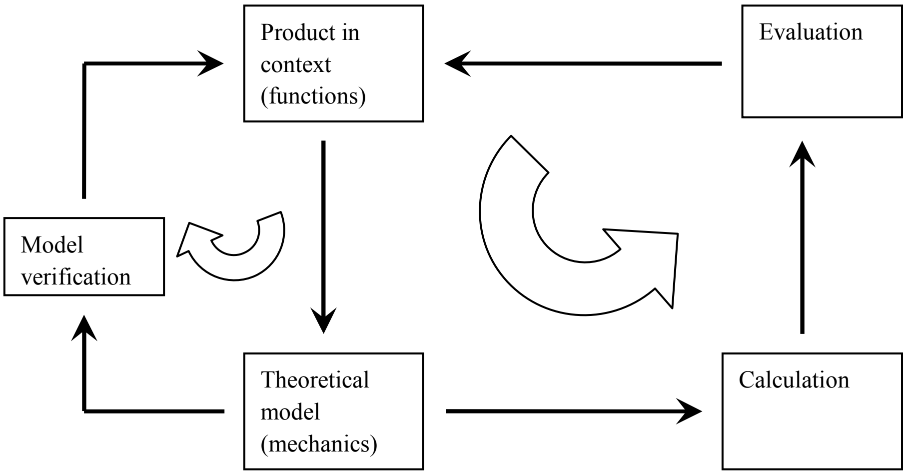

Figure 2 Steps of the modeling process

It is crucial for students to understand the applicability of the analytical model. They must be aware of the applied mechanics domain and the basic limitations. E.g. mechanics theory will be restricted to small displacements, while in much consumer products the displacements are going far beyond this limit. Even stronger, strength and stiffness of products like the bottom of some plastic crates can be fully attributed to the curved geometry of the deformed bottom.

With some effort it is possible to tackle the above mentioned problem by applying upper and lower limit solutions. However, for such problems the finite element method (FEM) is a well-known and very attractive tool and students will meet this numerical method during the courses. But, the students will learn the backgrounds of the method only very limitedly and so we have to elaborate a method to use this tool in a responsible way. Beyond dispute, a student must be informed about the model (Free Body Diagram with relevant boundary conditions) that he has to define when he wants to use a FEM program to solve a particular problem. Therefore, at the start the method will be taught with a common FEM program instead of one of the very user-friendly plug-in program. Of course students have the opportunity to learn more about FEM during their master.

We want the students to exercise in modelling and mathematics. Therefore, in many exercises and in the final examination we will ask them not to use rules of thumb and practical rules. Of course, this is different to the professional practice. A designer of a snap-fit will not start from the differential equation of a beam deformed by bending, but will use the standard formula of a beam fixed at one side.

However, a designer with a scientific education must be able to handle situations where practical rules are not sufficient. In such a situation modelling skills will have to be used to establish and solve a theoretical model. As a result of the intention described here, we have to develop a huge amount of new exercises.

Starting-point is to teach mathematics subjects in the courses where it is useful for basic theoretical disciplines, mostly mechanics. The direct applicability will determine the composition and order of the mathematical parts. Algebra of matrices has therefore almost been removed. During the last mandatory course in the second year students will learn to apply their modelling knowledge in a broader physical area and again mathematics (1.5 e.c.) will be fine-tuned with the objective mentioned above [1].

3 COURSE COMPOSITION

The composition of the courses is still subject of discussion. However, starting point is that no separate mechanics, mathematics, materials science, etc. courses will be presented. All these subjects will be integrated in a new series of courses. Four of the sixteen mandatory courses will be fully engineering design courses. These are specified below. In some other mandatory courses, engineering design is combined with other disciplines like ergonomics, formgiving and marketing. This is, because integration of disciplines is not restricted to the new engineering design subjects, but it is starting-point of the entire bachelor revision.

3.1 Course 1 (Product Functioning)

This course includes 1.5 e.c. mathematics and 2 e.c. mechanics (statics).
The course will be an introduction in engineering design. Emphasis is on the functioning of products. Not only statical functioning of products like garden chairs, plastics crates, etc. are taken into account, but also dynamical functioning of products like bicycles, electrical tools, etc. The mechanics part of the course almost completely consists of statics, that means equilibrium of forces is the central issue. This is very traditional and it seems a bit strange to use statics for dynamic product modelling. However, a quasi static approach is quite common and often sufficiently accurate. At the end of the course the tensile curve and the concept of uni-axial stress will be introduced. In the current curriculum vector calculus is taught by both mathematics and mechanics lecturers. In the new curriculum only the mathematics lecturers will teach the theory of vector calculus using mechanics vectors for explanation and exercises. As a result, the mathematic lecturers have to learn some mechanics, and the mechanics lecturers will skip this part. Concerning mathematics, students will be taught to use Maple (a mathematics software package) and the concept of matrix will be introduced.

3.2 Course 2 (Product Engineering)

The course includes 1.5 e.c. mathematics and 1.5 e.c. mechanics (statics and mechanics of materials 1).
The course will finish the statics part, will elaborate the concept of stress (bending and torsion) and will treat geometrical parameters as static moment, centre of mass, moment of inertia for areas, etc. Traditionally, these are all mechanics subjects, but in the new course the mathematics lecturers will treat the geometric parameters as a practical application of the integration calculus. Mathematics will also deal with partial derivatives, but at the moment it is unclear how to integrate this subject with mechanics. The course will continue with engineering design subjects with an emphasis on bending and shear stresses, including torsion.

3.3 Course 3 (Product and Movement)

The course includes 1.5 e.c. mathematics and 1.5 e.c. mechanics (dynamics).

The course will deal with product movements that must be controlled. As a result, dynamics is a logical subject. Dynamics of particles and rigid bodies, mass-spring-damper systems, conservation of energy and momentum will be taught. The latter is applicable to the impact behaviour of products. Mathematics will deal with first- and second-order differential equations. The mass-spring-damper theory will be taught by mathematics lecturers and not by mechanics lecturers.

3.4 Course 4 (Technical Product Optimizing)

The course includes 3 e.c. mechanics (mechanics of materials 2).

The course will finish the mechanics of materials subjects. Each week, the course will focus on a particular field of sub-optimization, such as minimum weight, reliability, function integration, durability, design for assembly, etc. The latter two do not have a clear relation with mechanics. However, the relation is very strong for sub-optimizations that highly depend on strength and stiffness, whether or not related to time and temperature.

4 DISCUSSION AND CONCLUSIONS

A series of courses have been composed in which mathematics and mechanics are integrated in engineering design. Starting point for all courses will be the design situation including the comprehensive field of theoretical modelling of real life mechanics situations. Therefore mathematics appeared to be an essential subject of the bachelor. It is worth-mentioning, that the traditional mechanics subject order of statics followed by mechanics of materials could be applied. By starting the exercise of each engineering design course with a real world design situation it is hoped, that students will apply the scientific modelling approach for obtaining quantitative results also in other parts of their study.

At the moment, mathematics, mechanics and engineering design lecturers are working in different faculties and are teaching separate courses. In the new situation they have to work together as well for composing new courses as for the actual teaching. In particular, mathematics lecturers have to learn some basics of mechanics. Much time is being used for discussions related to the teaching program and educational techniques for the courses. Fortunately, all lecturers are enthusiastically contributing to the new courses.

As a result of the integrated approach subjects will be taught once, and not twice (by mathematics and mechanics) as in the previous situation. Moreover, mathematics will apply as much as possible mechanics in the exercises. Mechanics will apply real life engineering design examples. This seems very efficient, but it is still questionably whether it will result in a reduction of study time. Students will still need time to absorb the theory.

The courses will be taught using a variety of educational forms like main-hall lectures, interactive class-room teaching, design oriented projects, self-education, etc.

Engineering software will be applied to increase the attractiveness of the course. The new objectives will require more individual coaching. However, lecturer capacity will not increase much and therefore extra electronic tutorial tools will be created to replace the teacher [2]. Moreover, a software program will be applied to follow the progress of each individual student during the course.

Examinations are always very determining for the learning behaviour of students. The examinations will be in accordance with our new objectives. Examinations will have a design context and all course parts will be integrated in one examination. It will not be allowed, to compensate e.g. a low score for mathematics with a high score for e.g. materials selection. For each course, the tenth week will be reserved for examinations.

It is expected, that the above-mentioned approach will improve the scientific base of the new bachelors and will supply industry with highly competent industrial engineers. Additionally, it is hoped that the design oriented character of the courses will increase student motivation and as a result the throughput of the bachelor.

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