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Abstract
On behalf of the construction of a continuous engineering education programme for computational and experimental mechanics, a number of didactical questions are answered, through a study of experimental educational conditions in regular university courses.
Most of the questions concern the influence of the use of the computer with advanced software concerning the speciality in question through students.
The main conclusion is:
The use of the computer with software in the fields of mathematics and control engineering does not without due consideration raise the insight in these specialities, but the motivation of students is raised through enhanced applicability of the theories. Therefore the course in Computational and Experimental Mechanics is focussed on a thorough understanding of the theoretical backgrounds of the subjects in question.

1. Introduction

"Continuous engineering education" (C.E.E.) as a university course is justifiable if in industry there is a permanent lack of relevant knowledge which is available at the university. The primary conditions for a successful C.E.E. programme will be then:

1. The formulation of the nature of this lack of knowledge
2. The organisation of the exchange of knowledge.

Both conditions will have to be fulfilled by industry in co-operation with the authorities in order to prevent this lack from developing into a technological retrogression. In the following an account is given of a close contemplation of the educational development in the speciality of "Computational and experimental mechanics" (C.E.M.) and its implications for C.E.E..

2. Rough decription of the developments in the speciality of C.E.M.

C.E.M. occupies itself with the prediction and the measuring and control of the mechanical behaviour of constructions. Roughly 4 essential phases can be distinguished in this, i.e.

Modelling
Solution–process
Interpretation
Verification

In the phase of **modelling**, the behaviour of a construction is described by a system of relations between the quantities that describe the relevant behaviour of the construction as well as possible. The final result of the phase of modelling is a system of mathematical equations with boundary conditions. In the phase of **solution**, this system is solved in order to quantify the quantities that describe the behaviour.

In the phase of **interpretation**, the solution is interpreted in terms of the behaviour to be expected of the actual construction. Taken into account are imperfections in both the model and the solutionprocess.

In the phase of **verification**, the results of the analysis are compared with the actual behaviour of a construction. In order to keep the costs of analysis as low as possible, for this comparison often a much less complex construction or part of a construction is chosen to which the same analysis is applied. Often too, this phase is dropped in the first instance. The development of digital computers has very much increased the potential in the phase of solution. Until recently, mechanics has been a relatively stable subject in which the training of students was focussed on the analysis of relatively simple constructions. The reason for that was that determining the solution of systems of equations was only possible for relatively simple systems. As the equations had to be solved analytically, the boundary conditions had to be simple, and there should be little or no interaction between the describing quantities. This means that the art of mechanics consisted of the correct prediction of the behaviour of complex constructions with the aid of insight obtained by analysis of relatively simple models of the more complex reality. **Insight into mechanics could be defined as the degree of proven correctness in predicting the behaviour of complex constructions on the basis of relatively simple analysis–techniques.** Complex problems go with complex systems of equations for which no more analytic solutions can be found. Then the behaviour of the construction can no longer be given explicitly as a function of the model parameters, and loading parameters. Then one has to switch to numerical methods of approximation which, in general, are characterized by large series of elementary arithmetical operations executed on discrete numerical values.

The descriptions of these manipulations are called algorithms. Because of the limitations inherent to the digital representations of numbers, a deviation from the analytical solution is introduced by the calculation itself. Owing to the ever increasing processing–speed for computers the development of algorithms for increasingly more complex systems of equations are stimulated. For the mechanical engineer this means that he can admit more and more interactions between the relevant quantities and increasingly more complex boundary conditions in the phase of modelling. Also as a result of this, new concepts and mathematical notations develop in order to be able to describe the complex systems of equations efficiently and analytically in a well–organized way. Besides, in numerical mathematics and in information theory new concepts are being generated all the time, which are of interest to the mechanical engineer.

The above means a continuous adaptation of schooling in which, among other things, new training–situations will have to be invented all the time, in order to become familiar with the renewed modelling and the solution of the consequent systems of equations.

The difference between the actual behaviour of a construction and the calculated behaviour of the complex model of the construction has four kinds of causes, i.e.

1. **Poor modelling**
2. **The inaccuracy with which the model–parameters have been determined**
3. **Poor algorithms**
4. **Machine–inaccuracy.**

.Today, difference 1 is, in general, smaller than it used to be as

there is less need for simplification. Higher demands are being made nowadays upon the accuracy which the model-parameters must be familiar with, on account of the refined modelling. The differences 3 and 4 can become very large under certain circumtances. Insight in this can be obtained by solving relatively simple numerical problems, aimed at obtaining insight. As increasingly more advanced software-packages, based on partly new concepts, come into the market, a lack of knowledge comes about with mechanical engineers who are assumed to work with this software. Coming into the market of new experimental methods and appliances for that, even reinforces this. Therefore, schooling will have to be adapted continuously and permanent education for mechanical engineers who work in the field of C.E.M. has become a compelling necessity.
Keeping up the development in the field of mechanics and measurement and control engineering relies to the university rather than to the industry as the efforts in this field are very labour-intensive, and very often not product-focussed. The results have in general, no short-term effect and are coupled with the development of didactics. The results of the research are transmitted to industry by a "continuing engineering education-programme Computational and Experimental Mechanics" (CEM).

3. The global objectives of the C.E.E. programme Computational and Experimental Mechanics.

The rough goals of the "computational" part of the C.E.M.-course are the provision of:

1. Skill in advanced modelling.
2. Knowledge of the power of numerical methods.
3. Knowledge of current limits of these methods.
4. Insight in the accuracy of the solutions obtained.
5. Skill in estimating the correctness of solutions.

The rough goals of the "experimental" part of the CEM-course are the provision of:

1. Skill in rationally planning of experiments.
2. Skill in determining the accuracy of experimental techniques.
3. Knowledge of the backgrounds of a distinct number of experiment-techniques.
4. Knowledge of the coupling of computational and experimental methods and results.

4. The educational questions that arise when making up a CEM-course.

When making up modern schooling in mechanics and in particular for the training in computational and experimental mechanics, apart from organizing questions a number of questions of an educational nature must be answered.

1. What is the substance of the schooling?
2. To what extent does solving problems with the aid of a computer contribute to deepening of insight?
3. Which remaining effects has solving problems with the computer?
4. To what extent is self-activity with the computer desirable?
5. To what extent are advanced professional black-box programmes suited for the realization of educational goals?
6. How should these global educational goals be tested?

The department of Fundamental Mechanics of the Eindhoven University of Technology (E.U.T.) has had its roots of research in the field of C.E.M. for many years. Therefore, there is subject matter in abundance. For the first course a programme has been drawn up by the lecturers which links-up with the knowledge of engineers graduated not longer than 10 years ago. The rough substance has been discussed with some 10 technical managers of some big industrial companies. The intention is to attune the schooling to the target-group in a better way in the next course, after evaluation. Because of the great diversity of industrial companies and opinions within them it is impracticable to previously come to attuning on a substantial level. Through contract research and contacts with the many graduates and graduate-work in industry, there is enough insight in the need of knowledge in industry. The questions 2, 3 and 4 refer to the form of schooling. The answers to the questions are of interest as the large-scale use of computers in education demand large material and personal investments. The answers to these questions have been obtained by extrapolation of the experiences in experimental courses in undergraduate schooling. The answer to question 6 has been obtained by contemplation of a continuummechanics-course within the CEE-programme (T.O.P.) (Top training polymer technology) at E.U.T.

5. The experimental educational conditions.

5.1 An experimental mathematics instruction.

In an experimental course calculus and linear algebra for first year's students in mechanical engineering, part of the students participate in an alternative educational programme in which personal computers and mathematical software were being made use of intensively. The other students got their schooling in the classic way. In the theory-lessons the theories and algorithms which were at the root of the exercises were treated. The experimental course has been designed by Simons [1].
At the beginning of this experiment it was expected that less training in solving problems analytically and more training in solving partly more complex problems with the computer would produce the same or more insight into the mathematics concerned.

5.2 An experimental instruction in control engineering

In the second form practical work in elementary control engineering was given in which the students made intensively use of a toolbox with procudures for the PC. The theory belonging to it will be treated in the lecture-form, see Kok [2]. At the beginning of this experiment the expectations were:

1. The insight into control engineering will be enlarged by application of the software toolbox with which more complex problems can be solved.
2. The practical applicability of control engineering will be enlarged strongly which will increase the motivation to study the subject.
3. Students obtain skill in working with a software package as an aid.

5.3 A C.E.E. course polymer technology

As part of one-year parttime C.E.E. course TOP for polymer technologists, lecturers of the division of Mechanical Engineering Fundamentals have taught modern continuums mechanics. In this part of the course, the stress has been put on analytic modelling with a view to later applications of numerical solution procedures when designing synthetic products. The objective of this part of the course is to provide insight into the backgrounds and potentialities of commercially available mechanics software, with which both the synthetic products themselves and the production processes for these products can be analysed. Expected here is that this insight will promote a multi-disciplinary approach to the polymer technology, which will lead to better synthetic products. Owing to the great number of course members and the limited computer facilities no computer-trainings were inserted.
The objectives were tested afterwards by written examining.

6. The conclusions.

6.1 From the experiment with the first years'course calculus and linear algebra, using personal computers the following conclusions have been drawn:

1. There are no indications that by using the used mathematical software more insight into mathematics is obtained than in the classic way.
2. The use of hard- and software in mathematics-schooling is motivating as the applicability of the subject is promoted.
3. The use of mathematical software in schooling makes clear that new concepts from numerical mathematics are needed. This will make schooling in numerical mathematics change. There is a shift from concepts and methods from analytic mathematics to those from numerical mathematics while the essential is maintained. This is a gradually proceeding process under the influence of using computers in education.
4. Training in analytically solving mathematical problems results apart from experience in solving such like problems, in insight and a deepening of the basic concepts. So far, solving suchlike problems with the aid of software has not yet become a good alternative to obtaining insight into mathematics and it does not simply lead to deepening of the basic concept.
5. If insight into mathematics, rather than routine-wise skill in a solution process, is to be tested, then the questionings when using software must become different from what they have been so far.
6. Training in using software requires more student-supervision and is therefore relatively expensive.
7. With a view to obtaining insight, computer training should be accompanied by guiding critical questioning. This fact makes the use of computers in education labour-intensive and consequently, even more expensive.

8. Automized instruction, with feedback, computer assisted instruction (C.A.I.) will be absolutely impracticable for some time to come, owing to the high speed of changes in mathematical schooling. The rapid developments in information theory coupled with long development–times for good C.A.I.–programmes are at the root of that. This goes certainly for a small linguistic area like the dutch.

6.2 From the experiments with the second form's practical work: control engineering with appropriate software, the following conclusions have been drawn:

1. The applicability of the subject is promoted by using software with which more complex problems can be solved more quickly then without software. Looking for alternative solutions by parameter–variation is mentioned as being a great advantage in this connection.
2. There are no indications that by using software new insight into control engineering is obtained. The impression exists, though, that by seeing more solutions to problems than in the classic situation, the existing insight is being deepened.
3. Working with a software toolbox works motivating owing to the larger applicability of the subject.
4. Using computers demands more intensive student–supervision than in a standard practical work situation.

6.3 The experiences in the C.E.E. training T.O.P. for Polymer–technologists lead to the following conclusions:

1. Graduated chemists are more motivated with regard to aquiring basic concepts and methods of continuum–mechanics than students in mechanics in the undergraduate schooling. This, despite the fact that they dispose of little foreknowledge and reference material.
2. With the course–members there is a certain resistance against testing insight and knowledge by means of written examining. Probable causes for this are: possible repercussions on the company that finances the course, and possible loss of face with fellow course–members.

6.4 The above conclusions have led to the following points of view in relation to the C.E.E. programme C.E.M. to be developed:

1. Insight into mechanics c.q. control engineering is mainly obtained by exercising in mathematical modelling, and insight into the accuracy of numerical solutions can only be obtained on the basis of understanding of the desribing algorithms and not by experience with the use of advanced commercial software–packages. Experience without insight leads to strong superstition or confusion, depending on the exercises presented. Both will eventually lead to failing analyses.
2. Confrontation of numerical solutions with analytic solutions for relatively simple problems works motivating. Software available on the market for matrix manipulations and other simple and cheap software for personal computers are usable for this.
3. Exercises with advanced commercial packages do not, indeed, deepen insight, but may elevate the motivation to obtain insight, as the applicability of the subject is enlarged with this. Attention should be paid however as appearances may be deceptive. Learning how to use these latest packages has not proven to be a problem in education practice, provided that the theoretical basis is mastered. With good software the command language for adressing these should be a detail that can be learned easily.
4. The question in relation to the testing of insight has not been answered satisfactory yet. There is no information on the spreading in the level of the course–members, nor is there any idea about the nature of the difficulties with the course–members. For this reason and to avoid scaring off the small number of course–members in the initial phase too much, written examination has been dropped.
5. As to the more expensive supervision, it is expected that with more experience and structuring and documentation of the excersises, improvements can be achieved in this.
6. C.A.I. is a useless auxiliary in C.E.M. schooling because of a high speed of changes in the developments of the subject, the very high labour–intensivity when developing professional C.A.I. modules that must collaborate with analysis–software and the high material costs connected with it.

7. The C.E.E. programme C.E.M..

The above–mentioned conclusions have found a reaction in the composition of a 1–year parttime training in C.E.M. Here three branches of coherent subjects are taught.

1. Continuum mechanics
   Fundamentals of continuum mechanics
   Numerical aspects of linear solid mechanics
   Numerical aspects of non–linear solid mechanics
   Numerical solution methods for problems of liquid flow
   Stability of constructions
   Microreology
   Mixture models
   Fracture mechanics
2. Dynamics, and control engineering.
   State space description
   Dynamics of mechanical systems
   Multibody dynamics
   Control engineering
3. Experimental techniques.
   Statistical methods
   Measuring of liquid–flow
   Static and dynamic characteristics of measuring systems
   Data–acquisition, –transport and –processing
   Measuring of strain and strain–rate distributions.

Besides, attention is paid to:
Numerical optimization of constructions.
In this course, the emphasis is on mathematical modelling, and on numerical solution methods. Attention is paid to knowledge of concepts, acquisition of insight into, and knowledge of the present limits, restrictions and application possibilities of software. In this course use is made of simple software for matrix manipulations and, besides, demonstrated are some six advanced software–packages. During the evening–hours experience can be acquired with these packages facultatively under supervision of E.U.T. lecturers. Here too, the emphasis will be on the understanding of backgrounds rather than acquiring experience in using specific software.

8. Discussion.

When announcing the training, from reactions it became evident that industry is insufficiently aware that for the use of advanced software special schooling is required which is not part of the university graduation programme. Cuts in education and shortening of the study duration are the cause that in the graduation phase the level of knowledge cannot be obtained which is necessary in order to be able to use advanced analysis software significantly. Besides, it is realized insufficiently that knowledge in the field of C.E.M. outdates relatively fast. In industry there is, moreover, the misconception that the use of advanced software will– or, at least, should– provide automatically the necessary insight into its working and backgrounds. Short courses in which no fundamental insight is taught but in which the subject is demonstrated with the aid of a software package, are relatively useless in this connection, but they are being asked for by industry, fundamental courses are considered too long and too expensive.
The price that society pays for the poor prediction of the working of industrial products, is falling behind technologically. The Netherlands have to content with an enormous waste of public money by not tolerating selection of first years'students on the ground of capability for the study. It may be wondered whether this money should not be appropriated better for financing supplementary education. Statistic inquiry shows that marks for mathematics are good predictors for the skill in mathematical modelling in elementary mechanics, see de Vree [3].

9. Literature.

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