

DEVELOPMENT OF AN EDUCATIONAL SOFTWARE TOOL TO SUPPORT MECHANICS MODELING DURING THE DESIGN PROCESS

Anton HEIDWEILLER¹, Eric VAN DER VOORT² and Gerald WISSE³

¹Delft University of Technology, Faculty of Industrial Design Engineering

²Itho Daalderop bv, Technology Department, Schiedam

³Delft University of Technology, Faculty of Mechanical, Maritime and Materials Engineering

ABSTRACT

The paper evaluates an online Modelling Tool that has been developed three years ago. The Modelling Tool aims to replace the tutor by asking relevant questions. The student must do the actual work. It is not an expert system and it does not know “the only correct answer”, but it provides the student with context-sensitive help. The tool starts with the actual design situation. It helps the student to define relevant real life situations geared to matters of strength and stiffness. After that it guides students through the selection of a particular situation, the translation to a mechanics model and subsequently a mathematical model, the simulation, and finally the evaluation including validation.

During the last four years, the tool has been used in the course Technological Product Optimization by about 400 students a year. The following conclusions were drawn so far.

- Course students showed their ability to apply mechanics modelling in a structured way during an engineering design process at least three times. The reports were far more complete and clear than the “collection of computations” students, in general, handed in before.
- The tool generates a structured report and provides the teacher with easy-access on student’s work. The great amount of time that tutors otherwise needed to figure out student’s intention was considerably reduced.
- According to a survey, the students experience the tool as useful for the modelling steps that precede the actual computations. This corresponds to the open character of the Modelling Tool.

Keywords: Modelling, software tool, engineering design, mechanics of materials

1 INTRODUCTION

Being able to construct and use scientific models is an essential problem solving skill in the field of physics and engineering [1]. Scientific models also play an important part in the context of industrial design engineering where it is used to predict product behaviour. The iterative, modelling process is shown in Figure 1. The different steps that can be distinguished are: establishing modelling goal; translation to physics model; translation to mathematical model; simulation; and validation and evaluation. In fact, last step is an activity that is repeatedly carried out during the modelling process.

Traditionally, in academic engineering education much attention is paid to the derivation and solving of mathematical models. Textbooks are very suitable for learning this kind of knowledge, but they are less suitable for the remaining steps of the modelling cycle. These steps are linked to the real life situation and therefore are more open in nature. Decisions and lines of thought are to a lesser degree based on fixed procedures or algorithms and calculations are hardly necessary, if anyway. Often more than one answer can be right. We experienced that students felt very uncertain in taking these more open steps of the modelling cycle. In addition to this, it cost very much time to give feedback to the students. This was firstly due to the great number of students (hundreds), each of them with an own design assignment or, if identical assignments were prescribed, with own considerations regarding target group, cost price, requirements, etc., and as a result with different choices regarding loading

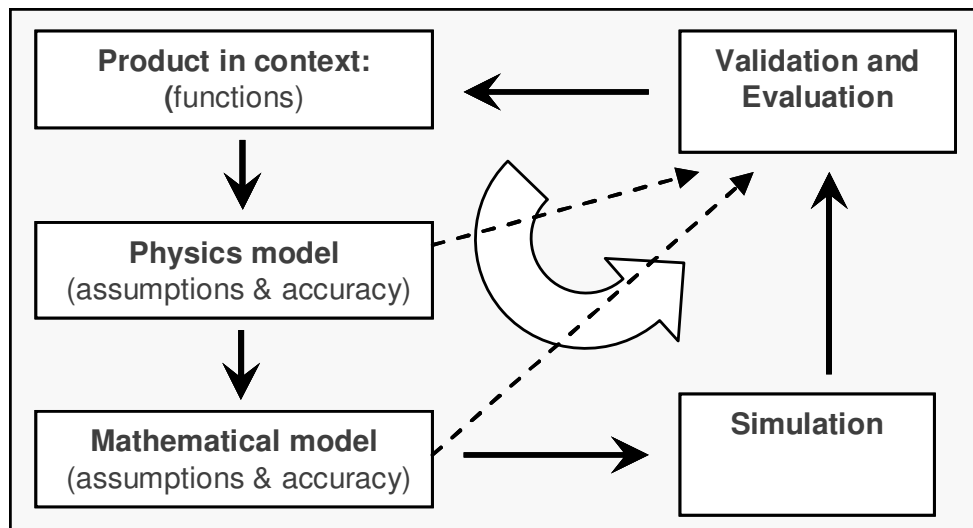


Figure 1. Modelling cycle as part of design process

situations. Secondly, students were so focused on arithmetical work that choices, lines of reasoning and the context of the computation were very unclear presented. Generally, the teacher could not understand student's modelling steps completely. These difficulties possibly explain why the complete modelling cycle got rather low attention in our industrial design engineering curriculum. As a result, too many students were missing the ability to use the mechanics theory, which they had learned before, in their design assignments later in their study. To remedy that situation, it was decided to develop a software tool that should be able to support students in learning the modelling cycle for mechanics of materials design problems.

We reported earlier about the development of the Modelling Tool [2]. The development is still going on, but it is running now for almost four years. Aim of the present article is to describe the Modelling Tool as it has been established and to present and discuss the results that have been achieved.

2 EDUCATIONAL OBJECTIVES

The software tool guides and supports students through the entire modelling process. It helps students to understand and experience that computations are only a small part of the modelling cycle and that seemingly exact outcomes are based on earlier choices, assumptions and simplifications. Based on our experiences, it was decided that in particular the following modelling capabilities of students had to be improved:

1. Considering various loading situations.
2. Translation of real life (design) situations into mechanics models.
3. Validation and evaluation.

2.1 Loading situation

Devising various loading situations and corresponding failure modes is a creative process, which requires sufficient attention. It is more than guts feeling. A loading situation with a high failure probability that is not taken into account can have unpleasant consequences for cost price, safety, liability, etc. On the other hand, the program of requirements needs to be selective.

2.2 Translation to mechanics model

Understanding the mechanics behaviour is a crucial step towards establishing a Free-Body-Diagram that matches with the design goal. Computations are normally not necessary at this stage. In fact, students get far with common sense and basic physical knowledge. An infinitely stiff or moveable joint, a ball-and-socket joint or another type of hinge: anyone can visualize the corresponding mechanics behaviour. However, in particular those students who are looking for an easy answer like standard formulae for the class of problems are inclined to leave out this step. Students should be focused more on this modelling step because it provides the necessary understanding [3]. It is in fact crucial for all other modelling steps in particular the validation and evaluation.

2.3 Validation and evaluation

During the whole modelling process there is interaction between, on the one hand, the choices that are made and, on the other hand, the validity of the model and the consequences for the design. In general, students have difficulties in applying simplifications. It is hardly conceivable that they don't like simplifications, but from the text book assignments they get the notion that all situations can be calculated. It is important that they learn to understand the necessity of simplifications, but simultaneously that they learn to realize the consequences of the simplifications. For example, what happens if a hinge doesn't behave as a perfect hinge or a floor is not perfect slippery in reality?

3 DESCRIPTION OF ENGINEERING MODELLING TOOL

3.1 General

Quaestio Survey Manager Software, a survey design programme, was used for programming the Modelling Tool. The tool guides the students through the modelling process by asking questions and in that perspective it replaces the teacher. In general, students don't need to answer the question, if motivated. After all, the Modelling Tool is a learning aid that tries to teach the students how to control the modelling process. A couple of times the students must answer a multiple-choice question, and then the answer influences the selection of the questions that follow. Learning takes place as the students become aware of the questions that they should ask and answer themselves. Students can answer by typing text or by uploading pictures. They can get context-sensitive help in the form of supplementary text and pictures and hyperlinks to the WIKI environment of Delft University of Technology. The results of the Modelling Tool are stored online and can be revised by the students during three months. The Modelling Tool can make a report for the students in pdf or HTML format. The set up and background of the Modelling Tool was described earlier in [2]. It is based on work of Hestenes [4], Halloun [1], Mauer [5], Etkina et al [6] and Pol et al. [7] and expert interviews with engineering teachers at our own faculty. The separate steps of the Modelling Tool are shown in Figure 2. Of course, there is an overall correspondence between Figure 1 and 2.

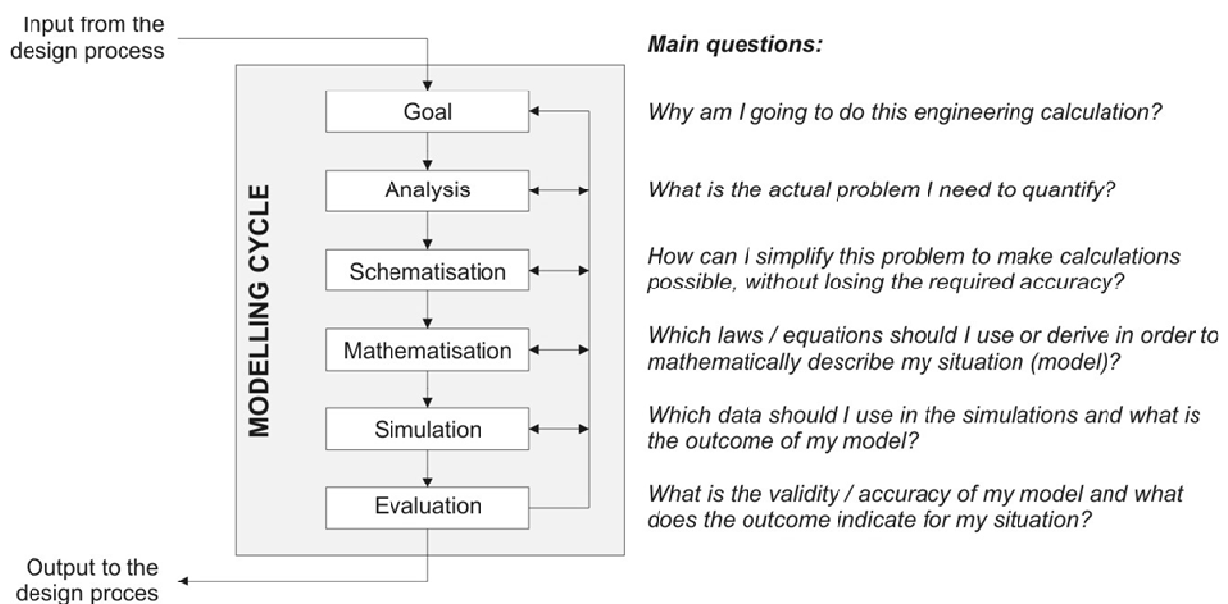


Figure 2. Modelling cycle and main parts of Modelling Tool [2]

3.2 Exemplification

Figure 3 illustrates the first three steps of the modelling cycle of Figure 2 for a strength and stiffness evaluation of a "polymer design coat rack".

1. In the first step the student is asked to explain the point of departure. What is more or less fixed on geometry, material, loading, etc.? The picture at the left of fig. 3 illustrates a usual loading situation according to a student pair. They assumed ten leather fur-lined coats of 5 kg each as a maximum loading for stiffness and strength. Other loadings, like "a child hang on the coat" were

considered but assumed to be less critical or too extreme. They also decided to focus on the vertical part.

2. The second step, analysis, is based on understanding the mechanics behaviour of the product under the chosen loading conditions. The student is asked to explain how the external loading is taken by the product and through the different parts transferred to the environment. Can the different parts take bending moment, torsion, axial loading? The second picture in Figure 3 belongs to this step. Arrows and accompanying text have been added by the authors. The student is also asked about the kind of loading (fluctuating, constant in time, etc.), kind of material (student pair chose for polystyrene: is that a brittle or ductile material?), stress concentrations, etc.
3. During the third step, schematization, the student is asked to present the free-body-diagram of the complete product (third picture in Figure 3 made by the authors) and the free-body-diagram of the critical part (picture at the right in Figure 3). It is crucial that the student is aware of the simplifications and the consequences. The present student pair based the mechanics model on linear (visco-)elastic material behaviour, modelled the vertical part as a beam and ignored any geometric nonlinearity like buckling in the vertical part. They shifted the angle in the field of the vertical part to the node. Unfortunately, they already did that before they started the actual analysis phase (step 2).
4. In the step mathematisation the student is asked for bending moment and other diagrams and for the formulas for stresses and displacements.
5. In the step simulation the calculations are carried out. In practice, calculations are carried out directly during the earlier steps. However, students are encourage to establish a parametric model, based on the formulas, and carry out a optimization based on chosen design variables. For this purpose a computer algebra system can be used like Maple or Mathcad.
6. In the step evaluation the student is asked about the realistic nature of the results; the accuracy and validity; to what extent the modelling goal has been achieved; whether or not the design have to be changed and if a new modelling cycle is necessary.

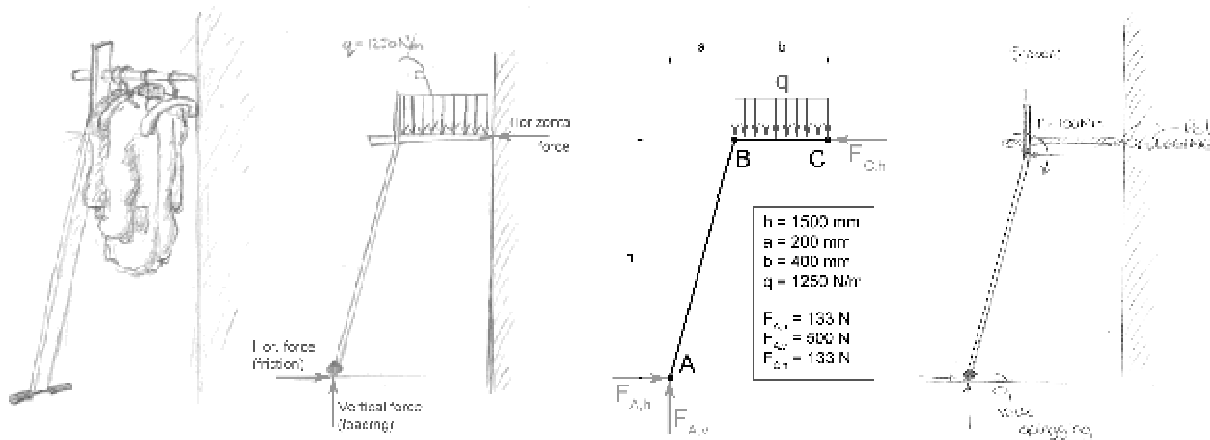


Figure 3. Illustration of the first three steps of Figure 2. That is, Goal (picture at the left), Analysis (2nd picture) and Schematization (Free-Body-Diagram of complete product and Free-Body-Diagram of vertical part)

4 RESULTS AND CONCLUSIONS

The basic question, did the Modelling Tool improves students modelling skills, cannot objectively be answered, because no benchmark data are available and complete Bachelor curriculum had been changed. The Modelling Tool was used for the fourth time by the second years Bachelor course “Technological Product Optimization” this term. The software was applied to conduct a survey into the Modelling Tool, the first time this term that the students used the Modelling Tool. The results of three questions are presented in Figure 4. The questions were:

Question 1: Using the Modelling Tool during this assignment, did it make you more aware of the importance of establishing the design loading before starting with computations?

Question 2: Using the Modelling Tool during this assignment, did it make you more aware that assumptions concerning the mechanics model are determinative for the outcome of the computations?

Question 3: Did the Modelling Tool help you in evaluating the calculation results?

These questions were about the three objectives that have been mentioned in section 2. The students did not answer extremely positively, however, only a few students answered that the Modelling Tool didn't help them at all. In general, the students react quite positive regarding the two questions about the modelling steps that precede the actual computations. The students answered less positive about help concerning the evaluation steps after the computations were carried out. This might be a consequence of the open character of the Modelling Tool. Most educational tools were set up for a well-defined domain and have the characteristic that the correct answer and process are known. Then very specific feedback can be provided.

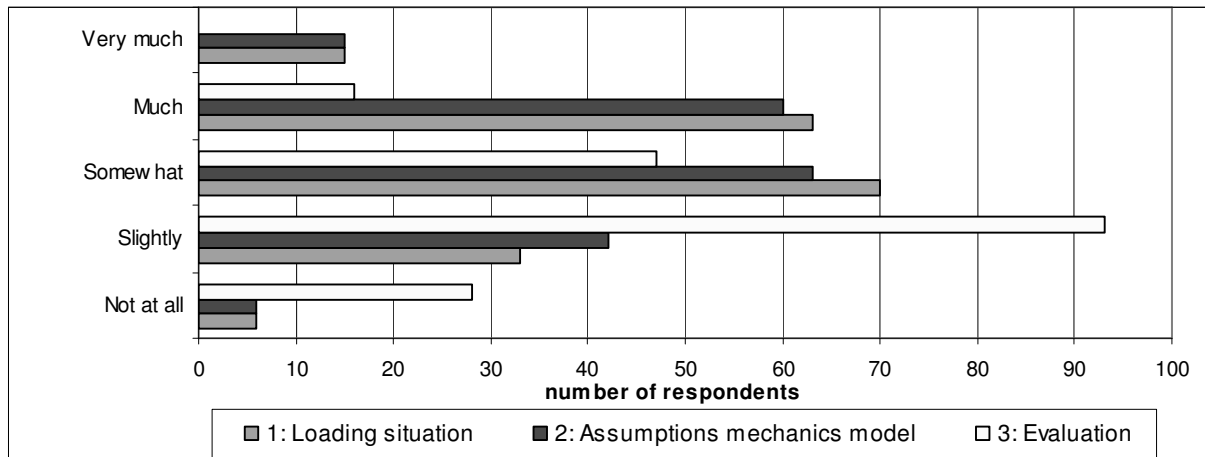


Figure 4. Survey into the Modelling Tool. The horizontal axis indicates the number of students that answered correspondingly for each question

Other conclusions from students and teachers observations:

- The structured report that is provided by the Modelling Tool is a great improvement for the teachers. The structured set-up makes it much easier to mark the reports. Information is by far more complete, in particular about the modelling steps that precedes the computations. The computations are much easier to follow.
- The user-friendliness of the Modelling Tool still needs much attention. A recurring reaction of students during evaluation meetings is that they recognize the usefulness of the Modelling Tool but they find it very time-consuming to use. Partly this is a communication problem. Students tend to elaborate their answers much further than asked for and are irritated if, later, the Modelling Tool still asked about the information already provided. This year, the students seemed to be more satisfied about the user-friendliness of the Modelling Tool. This is probably because it was emphasised more this year, that the tool is a learning aid for the modelling process and not an expert system. Students themselves remain responsible for the results and therefore must express their opinion about the relevance of questions. Nevertheless, adequate communication using text and pictures and explaining the background of the question is very challenging for a tool like this.
- The Modelling Tool guides the students to static determined beam models. This fits well with the mechanics theory that is taught to our students and with the theoretical knowledge of engineering designers in general. More complicated mechanics models can be calculated by specialists; however, also these types of calculations need a simple overall check. Besides, closed systems linked with textbooks can be very useful in learning to handle complicated mechanics models.
- It would be interesting to investigate the mechanics modelling quality of the students in the design courses that follow.
- It would be interesting to investigate the generic character of student's modelling skill. Are students able to use their obtained modelling knowledge in other disciplines as well, like thermodynamics, electronics, etc. Several authors have mentioned this additional advantage [1].

ACKNOWLEDGEMENTS

This project is supported and funded by the 'WO Sprint initiative' from the Dutch government. This initiative aims at improving (the impact of) science and engineering education and promotes it amongst scholars and students.

REFERENCES

- [1] Halloun, I. Schematic Modeling for Meaningful Learning of Physics. *Journal of Research in Science Teaching*, 1996, 33(9), 1019-1041.
- [2] Van der Voort, E., Heidweiller, A., and Coninx, K., Development of an online coaching tool for mechanics of materials analysis in Design Projects. In 10th International Conference on Engineering and Product Design Education, E&PDE 2008, Barcelona, 2008.
- [3] Hung, T.C. et al. An innovative improvement of engineering learning system using computational fluid dynamics concept. *Computers and Education*, 2007, 48(1), 44-58.
- [4] Hestenes, D. Toward a modeling theory of physics instruction. *American Journal of Physics*, 1987, 55(5), 440-454.
- [5] Mauer, G.F. An interactive visual environment for scientific problem solving. In ASEE Annual Conference Proceedings, pp. 1769-1779 (2001).
- [6] Etkina, E. et al. The Role of Models in Physics Instruction. *The Physics Teacher*, 2006, 44(34), 15-20.
- [7] Pol, H. et al. Solving physics problems with the help of computer-assisted instruction. *International Journal of Science Education*, 2005, 27(3), 451-469. van Wezel W. and Jorna W.J. Paradoxes in planning. *Engineering Applications of Artificial Intelligence*, 2001, 14(3), 269-286.