DEVELOPMENT OF A KNOWLEDGE-BASED TUTORING SYSTEM TO SUPPORT MECHANICS MODELLING DURING THE DESIGN PROCESS

Eric van der Voort[1], Anton Heidweiller, Katrijn Coninx and Hans de Deugd
[1]Delft University of Technology, Faculty of Industrial Design Engineering

ABSTRACT
This paper discusses the motivations for and development of a knowledge-based tutoring system (KBTS) that focuses on the quantitative modelling of mechanics aspects in product design. The main goal of the software system is to support both teachers and students in the new Bachelor engineering courses, as well as in design projects. The KBTS will provide a structured modelling approach that motivates, supports and inspires students in their modelling process and also provides the teacher with easy-access on the student's progress, in order to assess and give feedback to the student. In this context a structured and logical approach is proposed and tested amongst students. Although user tests are currently being performed, some preliminary findings are reported.

Keywords: knowledge-based, tutoring, modelling, design engineering, mechanics

1 INTRODUCTION

At the faculty of Industrial Design Engineering (IDE) of the Delft University of Technology (the Netherlands), a new Bachelor curriculum will start in September 2007. The Design Engineering department will radically change the way engineering courses, such as mathematics, mechanics, materials engineering, construction and production technology, are taught and assessed. In short, the transformation focuses on the integration of engineering theory and design practice. Integrative courses will focus on product analysis and product design through the theory of different disciplines. The main goal is to improve the quality of engineering education by making it more appealing and relevant to the students. Additional goals are an increased throughput of students in the Bachelor engineering courses (higher efficiency) and an increased transfer of knowledge from these courses to other design courses and projects.
The Bachelor engineering courses will also focus more on quantitative modelling in product engineering; an area that is essential to the success of many products and at the same time proves to be very difficult to a majority of students. Modelling a design proposal, be it mechanics of materials aspects, its thermodynamics or even the product's main function, is a process that can not be taught from textbooks, but should be experienced and implemented in the design practice. However, a foreseen problem in this design oriented engineering education is an increased amount of tutoring time. Previous attempts in this area have often failed because of this reason. Within this

context, a project has been started to develop a software tool that is able to support both students and teachers in the new engineering courses.

2 PROJECT DESCRIPTION

2.1 Motivations

Traditional science and engineering education typically consists of textbooks describing the theory, classroom lectures, homework assignments and an exam with similar assignments at the end of the course. This approach and its two main flaws seem to be universal and are acknowledged and described throughout literature. The first flaw is that engineering education typically focuses on analysis and abstract mathematical derivations rather than design, which often decreases the perceived relevance and motivation of students [1, 2]. Secondly, science and engineering students do not typically receive explicit training in scientific problem solving or modelling [3-5]. With the traditional way of education, students encounter several difficulties in applying theory to solve real-world problems. Instead of fully grasping physical phenomena and laws, using a systematic and logical solution path to solve problems and exploring multiple design alternatives, students very often tend to get stuck in 'formula picking strategies' and carrying out routine calculations without relating their findings to the real world.

Changing the traditional way of education towards a more design and modelling oriented curriculum is now widely perceived as a way to improve engineering education [1]. However, this combination of engineering theory and design practice that will guide our new Bachelor courses, poses difficulties to both students and teachers:

- Students will be asked to apply the theory in their design projects and solve real-world problems that are unlike the 'standard problems' found in textbooks. Many students will experience difficulties in tackling these types of problems, which is partly caused by a lack of modelling skills.
- Teachers only have a limited amount of time available for their courses and students. However, a design-oriented approach will cost more time to create, supervise and evaluate. Individual design projects are most time consuming as each design proposal differs from the next and the modelling process should be reviewed more than once to provide useful feedback to each student

These difficulties are the main motivations for developing a knowledge-based tutoring system (KBTS) that supports students and teachers in the engineering courses and design projects.

2.2 Goals

From the motivations described above, two main goals for this project have been stated:

1. Development of a KBTS that a) partly replaces the tutor by providing a structured modelling approach and context specific information, b) provides the teacher with easy-access on the student's modelling process in order to assess and give feedback to the student, c) offers a user-friendly interface that inspires students to create, explore and evaluate various design options, d) activates and supports students during their modelling process and motivates them to investigate the specific topic(s) more thoroughly, and e) encourages students to use parameterizations and quantifications as a design tool.
2. Implementation of this KBTS in the new Bachelor curriculum at the faculty of

IDE, so that both students and teachers benefit from the above mentioned advantages and continue to do so in other courses and projects throughout the curriculum.

Based on these goals, Figure 1 shows the three areas that play a key role in the KBTS.

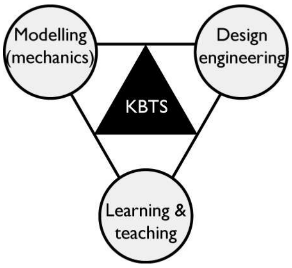

Figure 1 Main areas involved in the KBTS

Although this tutoring system could be an interesting tool for most engineering subjects, we will focus on 'mechanics' first, as our new curriculum will pay much attention to this area and it also provides a rather structured classification of topics. Focussing on a specific area also increases the chance of success for the implementation of the KBTS.

2.3 Approach

The development of the KBTS will take 1.5 years (starting January 2007) and consists of three main phases. In the Analysis phase the main topics involved in the project (Figure 1) will be investigated thoroughly through literature reviews and expert interviews. In addition, user tests will be performed early in the project to explore the student's and teacher's needs. The Analysis phase will be concluded with a functional description of the KBTS, an implementation plan and corresponding criteria. Next, the Design phase will comprise the actual development of the KBTS. Again, user tests with both students and teachers will be performed to check if the proposed solutions are justified. In the Implementation phase a first version of the KBTS will be implemented in the curriculum and tested in an actual educational setting. Results from this test will be used to optimize the KBTS. At the end of the project the KBTS should be able to operate autonomously according to the functional description and criteria.

3 CURRENT RESULTS

3.1 Educational software

The KBTS that is to be developed is a type of educational software (ES). ES includes all software that is intended to support the learning process and involves some form of interaction with the learner [6]. A literature review has provided an overview of research activities on the use of computer technology in engineering courses and has revealed several interesting types of ES: (interactive) multimedia environments that allow students to study a certain subject at their own pace and to their own extent [7-10], Intelligent Tutoring Systems that provide a 'personal evaluation' of the student's learning process [11], homework tools that supports students in making homework assignments [5, 12] and virtual laboratories that allows students to 'build' (virtually) and simulate a certain design proposal or problem situation [2, 13]. In the context of our project, the 'articulate virtual laboratory' from Forbes et al. [1] is most interesting in the

sense that each student is able to 'build' his or her own thermodynamical system from a set of standard components. 'Articulate' indicates that Artificial Intelligence techniques are used to understand the domain being learned, so that the software is able to provide context-sensitive information and coaching in a general manner.
However, none of these ES types entirely cover the function of the KBTS that is to be developed. Still, from the reviewed literature four important characteristics can be derived:

- Active; the student is able to build (model) and simulate interactively with information, problems or their own designs
- Open; the software tool is open to each individual problem or design and is not limited to a predetermined set of assignments
- Intelligent (didactics); students receive useful feedback, hints and additional information at appropriate moments that helps them to make decisions on their own
- Structured; the software tool aims at providing a general and logical structure for the modelling of (physics) problems, rather than giving answers to 'standard problems'

3.2 Modelling mechanics aspects in product design

In the context of this project, a model is seen as a simplified representation of a real-world phenomenon, which is not reality itself, but can be used as a way of describing, explaining and making predictions. Being able to construct such scientific models is an essential problem solving skill in the field of physics and engineering [4].
Based on the work of Hestenes [3], Halloun [4], Mauer [5], Etkina et al [14] and Pol et al. [15] and expert interviews with engineering teachers at our own faculty, the following modelling approach is proposed:

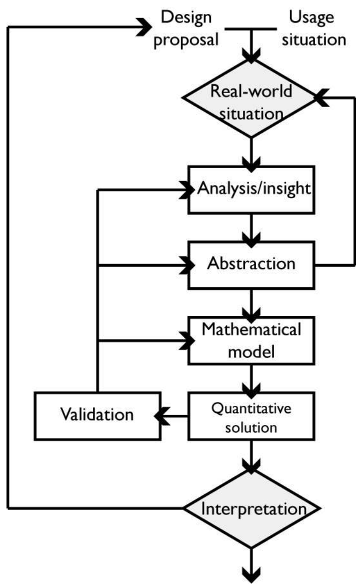

Figure 2 General modelling approach

Figure 2 shows that the real-world situation of interest, which is the starting point of the modelling process, is established by combining a certain design proposal and usage situation (mechanics threat). In the first step, this situation is analysed and the modelling purpose and questions, expectations and important (quantified) criteria are stated. The situation is then abstracted to a Free Body Diagram that represents the parts, loads and boundary conditions that are of importance to the specific modelling purpose. Subsequently, a mathematical model is chosen or derived that best 'fits' the situation. A plan that gives the substeps for solving this mathematical model is also devised and subsequently used to solve the model. Assumptions and simplifications are recorded carefully throughout these steps, so that the quantitative solution can be validated in the context of the situation. Finally, the solution is interpreted and design consequences are stated. Figure 2 also clearly shows the iterative nature of this approach, both in checking the validity of the modelling process, as well as in making design decisions.

3.3 User test on the modelling skills of students

Currently, a user test is being performed with 2nd and 3rd year IDE students who have completed the courses 'statics' and 'mechanics of materials' from the current curriculum. Each student receives the same individual assignment, in which they are asked to make a quantitative judgment on two parts of a product concept. All students receive 'traditional support' (the books used in these courses). In addition, half of the students directly receive the structured approach described in the previous section, consisting of a small (paper) dossier, with each folder presenting a single step in the modelling process and providing context sensitive help. The other students receive this structured approach only after they have finished the first part. At this moment, a pilot of two students has been performed with the use of this dossier. Some preliminary findings are stated below:

- One student initially refused to use the structured approach as it consisted of too much text; he would rather match his problem to other 'visually presented' problems. He also indicated that he is not used to these 'open' types of questions, as the mechanics books used in the course only contain well defined problems. However, when the observer coached this student through the structured approach, without giving away actual answers, progress was clearly made.
- The other student did use the structured approach when it was offered to him in the second part and found it to be of great value to his modelling process, especially the context sensitive help.
- Both students' initial approach was to find standard situations in the mechanics books and trying to adjust the real situation according to that standard situation.
- Both students also tried to find standard formulas in the mechanics books that would result in the desired solution. However, the concepts underlying the formula were clearly unknown to the students.

4 DISCUSSION

In this paper we have tried to give an overview of our project on the development of a knowledge-based tutoring system (KBTS) for modelling and quantifying mechanics aspects in the design process. We belief that this KBTS will be able to play an important role in the new Bachelor engineering curriculum by supporting students with their modelling process and teachers with their tutoring process. The preliminary findings from the user test and reactions from both students and teachers support our beliefs. We acknowledge that the basic concepts and laws of mechanics, or any other physics topic, should still be taught to students before they can apply it in the real world.

In the coming months our research will focus on the students' and teachers' needs, the modelling process, possibilities for software support and implementation issues. The results will be presented at the conference.

REFERENCES

[1] Forbus, K.D. et al. CyclePad: An articulate virtual laboratory for engineering thermodynamics. *Artificial Intelligence*, 1999, 114(1-2), 297-347.

[2] 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.

[3] Hestenes, D. Toward a modeling theory of physics instruction. *American Journal of Physics*, 1987, 55(5), 440-454.

[4] Halloun, I. Schematic Modeling for Meaningful Learning of Physics. *Journal of Research in Science Teaching*, 1996, 33(9), 1019-1041.

[5] Mauer, G.F. An interactive visual environment for scientific problem solving. In *ASEE Annual Conference Proceedings*, pp. 1769-1779 (2001).

[6] van der Mast, C. Developing educational software, integrating disciplines and media. (TU Delft, Delft, 1995).

[7] Soh, C.K. and Gupta, A. Intelligent interactive tutoring system for engineering mechanics. *Journal of Professional Issues in Engineering Education and Practice*, 2000, 126(4), 166-173.

[8] Avouris, N.M. et al. Development and Evaluation of a Computer-Based Laboratory Teaching Tool. Computer *Applications in Engineering Education*, 2001, 9(1), 8-19.

[9] Anderson, E. E. et al. Implementing and assessing computer-based active learning materials in introductory thermodynamics. *International Journal of Engineering Education*, 2005, 21(6-PART I), 1168-1176.

[10] Sidhu, S.M. and Selvanathan, N. A TAPS interactive multimedia package to solve engineering dynamics problem. *Campus-Wide Information Systems*, 2005, 22(5), 275-289.

[11] Chau, K.W. Intelligence-based educational package on fluid mechanics. In *Lecture Notes in Computer Science*, pp. 756-762 (Springer-Verlag, Berlin Heidelberg, 2005).

[12] Philpot, T.A. MDSolids: Software to Bridge the Gap between Lectures and Homework in Mechanics of Materials. *International Journal of Engineering Education*, 2000, 16(5), 401-407.

[13] Tucho, R. et al. Expert tutoring system for teaching mechanical engineering. *Expert Systems with Applications*, 2003, 24(4), 415-424.

[14] Etkina, E. et al. The Role of Models in Physics Instruction. *The Physics Teacher*, 2006, 44(34), 15-20.

[15] Pol, H. et al. Solving physics problems with the help of computer-assisted instruction. *International Journal of Science Education*, 2005, 27(3), 451-469.

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[1] Eric VAN DER VOORT, MSc
Delft University of Technology
Faculty of Industrial Design Engineering
Department of Design Engineering
Landbergstraat 15, 2628 CE Delft
The Netherlands
e.j.vandervoort@tudelft.nl
+31 (0) 15 2783034