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INTEGRATION OF SIMULATION INTO PRODUCT DEVELOPMENT AT AUSTRIAN SECONDARY AND TERTIARY TECHNICAL EDUCATION

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ABSTRACT

Product development today is primarily driven by virtual methods and can therefore be assigned to virtual engineering. Various software systems are available on the market, on the one hand with embedded CAD systems and on the other hand with stand-alone systems. A major challenge in secondary and tertiary education is to combine virtual engineering methods with general engineering knowledge. This results in the quality issue of teaching how to use the software and teaching the generally applicable knowledge behind the software solutions - i.e., the methods must be taught.
At Austrian HTL (secondary higher vocational schools), there is a strong focus on CAD during five years of education. In recent years, some aspects of virtual engineering have been taken up to prepare students well for working life. However, it is widely recognised that this needs to be strengthened. The paper will present the current state-of-the-art and show possible scenarios for improving the current state. At the Graz University of Technology (tertiary level), there is the situation that students have very different prior knowledge at the beginning of their studies (mainly mechanical engineering), as some of them come from HTL. An e-learning approach for CAD and CAE education was introduced in 2012 at TU Graz to counteract this and better adapt the teaching to the student's skills. As a result, a lot of experience and feedback have been gathered to improve the teaching approach continuously. The article shows this approach and outlines future perspectives.

Keywords: Virtual engineering, secondary education, tertiary education, CAE education, FEA

1 INTRODUCTION

The first steps in the field of CAx[1] were taken by Doug Ross in 1950 with the development of the Automatic Programming Tool (APT), which can be seen as the foundation stone for modern CAM systems. At the beginning of the 1960s, Nastran opened up the field of finite element methods [2]. About ten years later, in 1970, the first steps in computer-aided product development were taken, with CAD models replacing conventional hand drawings. In the first years, these models were limited to 2D geometry and extended to creating 3D geometry about ten years later. Since then, computer-aided tools have been developed for almost every subject area, thus providing the foundation of modern product development [1].
Students follow a similar path to the development of CAD tools in Austrian HTL. They also start their education with 2D hand drawings, which later in their education are transferred to 3D models with CAD programs [3]. Students at technical universities in the field of mechanical engineering also follow this learning process. However, the training at the universities does not end with a 3D model of a product assembly. Still, this model serves as a basis for structural-mechanical-dynamic investigations using, for example, finite element analysis (FEA[2]).

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[1] The term CAx summarizes Computer Aided Design (CAD), Computer Aided Engineering (CAE), Computer Aided Manufaturing (CAM), Computer Aided Styling (CAS), Computer Aided Planning (CAP) and Computer Aided Quality (CAQ) [1].
[2] FEA, an acronym for Finite Element Analysis, refers to a numerical method for solving differential equations in engineering and physics [4].

Through the results from an FEA, for example, displacement, stresses or reaction forces can be calculated and visualised on the previously created 3D model. This is often a moment of great importance for many students as they get a visual representation of the deformations, stresses or forces for the first time in their education. Since this link between the mechanical calculations and the visually easy-to-grasp FEA results in graphs strongly supports the learning process, it can be concluded that using FEA even earlier in engineering education to understand better-taught content can be very important and helpful for the learning process. That was derived from the CAD approaches outlined in [5].

This linked learning could also be used in theory classes in HTL to transfer the results of basic mechanical calculations into a model to make the learned material more tangible. Particularly, advanced-level students possess the necessary theoretical foundations to carry out such investigations, such as analysing stress curves in loaded components or examining deformations on a workpiece. In addition, it can be shown to the students how they can check entire assemblies for their loads with little effort without having to do pages and pages of calculations.

Of course, the field of application of FEA can be taught much further. Still, this paper is limited to dynamic structural-mechanical investigation since this topic is most widespread in engineering and is most tangible in HTL education. For the execution of FEA, the focus is put on the use of FEA in embedded CAx programs such as CREO from Parametric Technology Corporation (PTC), Inventor from Autodesk or CATIA from Dassault Systemes.

This paper's investigations focus on analysing the actual state of CAE education at HTL and Austrian universities. Thereby it is shown which gaps and approaches exist in the respective CAE education and how these can be closed. Since this is a larger topic area, further follow-up papers are planned (shown in chapter 4.2), which will deepen these investigations and approaches and still establish the conclusions to industrial partners.

2 STATE-OF-THE ART

This section compares possible approaches to CAE training. In the attempt to find a comprehensive training concept, a theoretical approach and a practical approach can be derived.

The theoretical approach is taught increasingly at universities [2]. In this scenario, great emphasis is set on the fundamentals of the FE-model theory. These fundamentals cover a broad spectrum ranging from the different mathematical solution variants of FEA selection of the appropriate element's discretisation to the abstraction of mechanical loading. The implementation of a model in a specific FE-Software is not considered. In the literature, no consistent training concepts specify a procedure that deals with the theory and the practical implementation. There are only standardised procedures for model implementation, as described in [4] [6] [7] [8]. However, the combination between theory and practical implementation is only presented very abstractly.

The practical approach focuses strongly on the application of the software packages. This approach is carried out in training courses of companies increasingly, specifically adapted to the CAx software used. The trainees learn the necessary procedures and the application of different tools. The theoretical background knowledge is partly neglected or assumed. The level of experts is often measured by the variety of tools by them and their skill in handling and operating the various programs and not by the underlying theoretical understanding [2].

At first glance, the practical approach appears to be more appropriate for the application and is also justified. The practical approach "promises" that a finished simulation model is available after the specified procedure is finished. This is also true because if all inputs required by the program are available, the simulation program resolves the inputs into a system of differential equations and solves them, so the software does its job per se. However, whether the simulation is able to represent reality depends on the skills of the person creating the model. A good FE engineer is characterised by the fact that he minimises the simulation effort by the correct omission of unnecessary information and still represents all phenomena to be considered. Finally, it should be mentioned that the simulation results alone do not provide any added value if they are not interpreted correctly with the appropriate engineering background and the knowledge gained derived from these results [1]. To do so, theoretical background knowledge is required accordingly. Therefore, CAx training should be more than applying a few "picks and clicks" [9].

Figure 1 shows the classical procedure of FEA generation in a software environment. In contrast, the right side shows which theoretical background knowledge is required to perform an FEA appropriately.

If all steps of the FEA procedure have been carried out correctly, the FEA delivers the stress present in the component. However, this result alone is only of limited value. The evaluation of stresses still depends significantly on various factors such as system knowledge, application area, desired safety factor and other relevant factors.

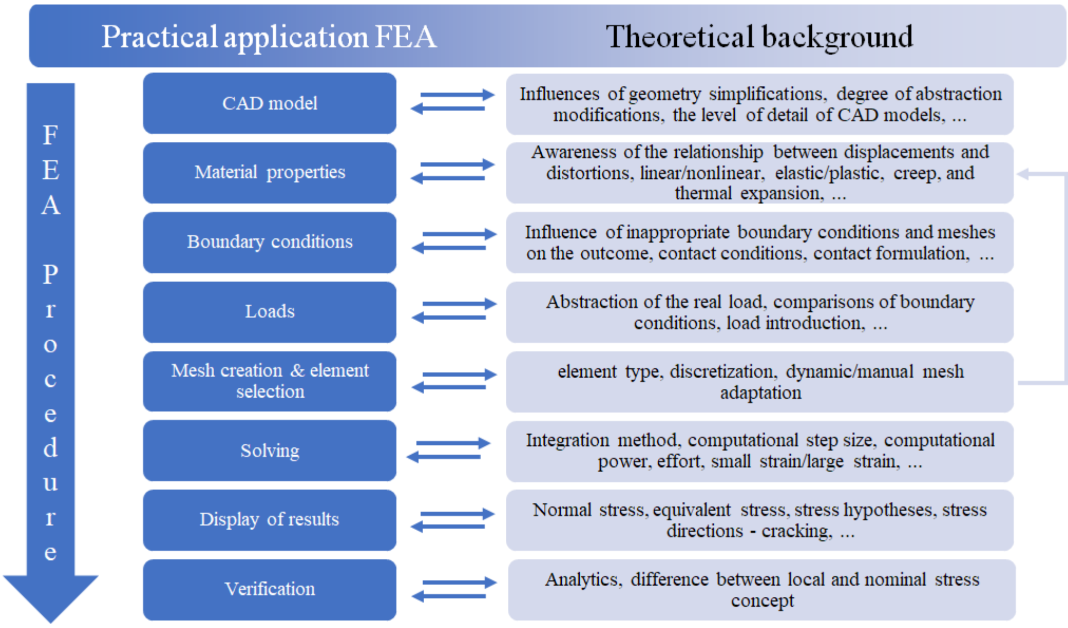

Figure 1. Required FEA theory for implementation in a software environment

To achieve meaningful simulation results, an FEA engineer has to be able to combine and interconnect theoretical and practical knowledge, especially since there is neither literature nor software that can evaluate the results with respect to the existing mechanical system represented by the FE model. An ideal CAx training should therefore combine method knowledge such as understanding the advantages and disadvantages of different CAx approaches, recognising the limitations in the modelling and interpreting results as stated in [2] with the needed practices using various tools and especially interlinking both of them.

2.1 Curriculum TU Graz and HTL

In order to get an overview of the current CAx education, the TU Graz serves as an example, where two hours per week are provided for students in the CAE lecture. In HTL, a capacity of two to four hours per week is available over five years for the design exercise area, which also includes CAD [10]. As universities have freedom in curriculum design, CAx education may differ from other universities of applied sciences. In HTL, there is a uniform curriculum per subject area, which can be designed autonomously within certain limits.

2.2 Actual state TU Graz – CAE teaching concept

In order to give a closer insight into the CAE education at the Graz University of Technology, the course of the CAE education will now be presented. The aim is to link the acquired basic knowledge, such as mechanics, dynamics and machine dynamics, with the working methods of CAE systems and thereby develop an understanding of the application and evaluation of theoretical analysis methods compared to modern simulation techniques. This is ensured by teaching theoretical basics and implementing examples in the areas of advanced CAD methods, finite element method (FEM) and simulation of dynamic systems (multi-body simulation MBS) with selected high-end engineering and CAE tools.
To be able to work with all students from the same foundation, the required theoretical knowledge is prepared in a lecture unit before the practical units, where the application of various simulation software is involved. For students with less prior knowledge, various online teaching resources are provided for self-study. This theoretical knowledge is further consolidated within guided practical units covering practical problems, which are abstracted and solved with the help of various simulation programs. In addition to these practice units, there are also "click-to-click" scripts, practice examples and learning videos on each topic for self-study. This parallel mode of guided practice units and e-learning allows

the students to practice using the software products in self-study, depending on prior knowledge and learning progress. The students are allowed to acquire the necessary contents and skills at a time and speed of their choosing according to their prior knowledge and newly acquired knowledge [11].

2.3 Actual state Austrian HTL - CAE

CAE training at Austrian HTL in mechanical engineering currently comprises more than 550 hours spread over five years [10]. The content is specified by the curriculum, which is jointly prepared by the HTL on behalf of the Austrian Ministry of Education and is evaluated and revised if needed, approximately every five years according to the prevailing educational boundary conditions.
Even though there is a strong emphasis on machinery design based on 2D drawings in training to meet the industry's requirements, the education regarding CAE can be seen as very solid. In the field of CAE, 3D modelling of components and assemblies is focused alongside state-of-the-art design processes as well as classical analytical design processes combined with the use of 3D modelling techniques.
The subject of FEA is taught only sporadically, often depending on the prior knowledge of the teacher. However, the technical fundamentals such as the strength of materials, fluid mechanics and thermodynamics are taught in the theoretical training. A linking of theory knowledge with FEA examples from the strength of materials, solid mechanics, fluid dynamics and thermodynamics is currently not being implemented consistently. The upcoming revision of the curricula starting in Austrian HTL 2023 offers the opportunity to include these important points. The use of CAE programs in theory classes is also being considered, for example, by visualising stress curves in a strength calculation or flow curves in flow calculations. Because Generation Z is strongly oriented towards visual information collection and progressing as well as learning in general [12], there is potential here to better convey the subject matter and to better understand and retain it. Visualising the results of mechanical calculations can help students learn how to apply theoretical concepts to practical applications. Seeing how their work leads to tangible outcomes and that their calculations have a real-world impact can increase their motivation and interest in mechanics.

2.4 Hypothesis - Gaps

Derived from the previously explained experiences, the following hypotheses can be formulated for further investigations:
H1: There are strong differences in the theoretical and practical knowledge of the students.
H2: Only theoretical basics are not sufficient to perform an FEA simulation in a meaningful way.
H3: The interconnection between taught FEA theory and practical application is missing.
H4: Application of theoretical knowledge increases learning success.

3 EVALUATIONS IN TERMS OF THESES

With regard to the hypotheses, this chapter is designed to verify them and should also show where further research is needed.

3.1 Experiences and Evaluations - Tu Graz

Experience in the CAE lectures over the last ten years has shown that students have a wide variety of theoretical backgrounds. To cope with the strong variation in this area, the previously explained CAE teaching concept was introduced at the Graz University of Technology. Statistical surveys have shown that over the last ten years, the content requirements of the course were considered appropriate by 72% of the students, which in turn reinforced the teaching concept. These results come from annual evaluations[3] of the course.
Furthermore, it was shown that even if the theoretical knowledge of the students is at the necessary level, the implementation of theoretical knowledge in practice is a major challenge. This can be deduced from the examination results. Students from higher semesters, who (theoretically) also have more prior knowledge, do not perform better than students from lower semesters.
Another observation, which is made repeatedly, is that it is often necessary to repeat theoretical basics during the exercise units. Therefore, the guided units in the CAE lectures cannot be replaced by

[3] Cumulative result of the course evaluations provided at TU Graz, carried out electronically, by the CAMPUSonline system [13].

instructional videos, tutorials or similar since the knowledge gaps can only be closed in dialogue together with the students and individually tailored to the corresponding students.
At the end of the course, it is shown that students are able to apply their theoretical knowledge to practical tasks. On the one hand, this is needed for the creation of the model, but also for the interpretation of the results.
It is worth mentioning that the aforementioned experiences were derived from strongly subjective, specific long-term experiences and surveys. Collected evaluation results of students from the past ten years serve as a further basis.

3.2 Implicit experience HTL

At HTL, the basics of mechanics are taught in great detail and in an age-appropriate manner. For example, the introduction to solid mechanics is taught at the average student age of 14, resulting in the need for simplifications. For example, forces are "only" considered 2-dimensionally and not spatially via vectors. So, in terms of hypothesis 1, the prior knowledge should be the same for the students. Also, hypotheses 2 to 4 are true from the author‘s point of view. The theoretical basics are clearly established at HTL in the field of mechanical engineering; the practical application takes place in the field of design exercises, but mostly without the use of FEA programs, mostly with the reference of the professors to the basics. The approach is certainly correct for the first strength calculation(s). However, from the authors' point of view, there is nothing to be said against using an FEA program for a repeated strength calculation in the area of design, especially since the analytical verification with the FEA results must always be carried out. First attempts to use FEA in mechanics education in the first classes of the HTL education show quite encouraging results and feedback since the current generation of students is strongly visually influenced [12], and thus the knowledge transfer is positively supported. Analogous to the use of FEA in the field of solid mechanics, an application in the fields of fluid mechanics, thermodynamics and vibration theory is conceivable and reasonable.

3.3 Transfer possibilities

In order to ensure continuous communication and coordination between the individual training programs, a working group consisting of Austrian professors from technical universities (TU), universities of applied sciences (UAS) and secondary higher vocational schools (HTL) was founded with the support of the Ministry of Science and the Ministry of Education. This working group aims to exchange and coordinate the current state of teaching and technology in the field of product development at least once a year in a face-to-face meeting and to develop joint strategies. Due to the different orientation of the individual institutions TU, FH and HTL, a very creative and productive working atmosphere is created in which innovations are made possible and promoted. One outcome is, for example, the participation of HTL in scientific projects at TU or UAS, such as Sparkling Science [14], with the aim of giving young technicians access to tertiary education at an early stage. On the technical side, standardised environments have already been exchanged and further developed in the area of CAD; in the future, this is also planned for the area of FEA. There is a great need for teaching materials and best practice examples, especially within HTL, in order to promote the introduction of FEA.

4 SCENARIOS AND PERSPECTIVES

Finally, this section presents the lessons learned, our further planned work, and an evaluation of the current results.

4.1 Learnings

Based on the evaluation results of the CAE lecture at the Graz University of Technology, it can be recognised that by continuously adapting the course, it was possible to reduce the level of difficulty and the amount of work while maintaining learning success.
Also, at the HTL, the change of the curricula shows further potential to adapt them in order to prepare the students for their further CAE education in the best possible way. Furthermore, FEA can also be used in the area of theory lessons in order to present theoretical knowledge to the students in a more tangible way. For example, FEA can additionally be used in mechanics classes to visualising calculated results such as displacements and stresses directly at the point where they occur on the component and be compared to classical analytical results.

Another finding is that the transfer potential between TUs, UAS‘s and HTL‘s exists but must be further expanded to meet the needs of the industry.

4.2 Aviso Paper-Series – Research design

In order to assess whether it is appropriate to include FEA in the HTL curriculum and which scenarios are feasible and reasonable, a survey is currently being prepared at the HTL. The opinions of teachers regarding different approaches to solving the hypotheses (Chapter 2.4) will be collected and evaluated. Further approaches are derived from this to close the existing gaps in education. These results will be presented in a follow-up paper (Place and time of publication are not finalised now).

In addition, a further paper is planned, which will also address the requirements of the industry. For this purpose, a four-year research project is available, which deals with intelligent, sustainable and human-centred (small and medium enterprises) SMEs[4] and collects their requirements and ultimately develops guidelines for SME‘s 5.0.

5 CONCLUSIONS

Through the research in this paper, the current state of CAE education at schools and universities regarding FEA was revealed. From this, different hypotheses could be derived, which addressed the gaps in education. The CAE training principle of the Graz University of Technology also presented a possible solution for linking theoretical knowledge with practical application.

Other transfer possibilities include the approach to including FEA already in the HTL curriculum. For further investigations in this regard, the design of the corresponding follow-up paper was also presented. In order to direct the focus from teaching to the "customer", the further planned paper serves to show the balancing act between teaching and industry.

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