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Electronic Learning Materials for Machine Design*

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Machine Design is the most perspective field of study in the Faculty of Mechanical Engineering (FME) at the University of West Bohemia with regards to the demand for graduates in this field. These days, the main issue of higher education in the Czech Republic related to Machine Design is the lack of opportunities for students of Machine Design to acquire practical knowledge and experience in the field. The problem is that engineering companies offer work experience only to individual students as they try to hire them after graduation. But engineering companies are not motivated enough to contribute to the Machine Design teaching process by providing knowledge and experience to the majority of students. As this is not going to change soon, universities have to provide real applications to its students instead. Currently, there are not enough opportunities for students to acquire practical knowledge in the field during their studies. The required amount of work experience for engineering students in the Czech Republic is only one week, which is insufficient in comparison with the German system, where internship semesters are a mandatory part of studying at a Fachhochschule (University of Applied Sciences). It is necessary to provide practical information and real applications in class to compensate for the lack of practical experience. FME is concerned in this matter and it has launched the project for enhancement of the teaching process. A new concept of electronic learning materials for Machine Design was developed as a part of the project. The learning materials were developed by academics in cooperation with local engineering companies to provide students and academics at FME with real design projects reworked for learning purposes. The Machine Design teaching process is complicated due to the complexity of the mechanical design process, as it has its own particularities which need to be considered while creating learning materials. When describing the mechanical design process, not only the design process itself has to be described. Also the production processes, project schedules, economic aspects of the design project, legislative, technical standards and regulations have to be described as well. As these parts of the mechanical design process affect each other, it is important to describe them in the context of the mechanical design process to show the interconnection between them. The electronic form of learning materials was selected as it offers many advantages over the standard printed form. The main reason for selecting the electronic form of learning materials is the ability to work with Computer-aided engineering (CAE) models. Three-dimensional CAE models replaced drawing boards in every engineering company several years ago and thus it is important to include CAE models in the Machine Design teaching process. Thanks to the technology of exporting CAE models to the standard portable document format (PDF) it is possible to modify CAE models for learning purposes and use them as a learning tool. CAE models can be enhanced with a large amount of information regarding a design project such as manufacturing processes, materials or component functions and can be supplemented by technical drawings, illustrated project descriptions and further information. All the learning material is converted into a single PDF file so that every student can access it anywhere, anytime. Versatility and interactivity are the biggest benefits of the new electronic learning materials. The new electronic learning materials can be used when explaining new subject matter to show its application, or as a basis for students' assignments, individual work, teamwork or dissertations. The sample electronic learning materials are being produced and will be made available to students through the courseware of the University of West Bohemia. This paper intends to present the learning materials and describe their form, structure and content and their benefits for academics and students of Machine Design.

Keywords: machine design; design projects; electronic learning materials; CAE models

1. Introduction

What do engineering students expect of their education? Actually, "few students would study engineering without expecting their education to help them prepare for engineering work" [1]. In recent years there has been a growing interest in the alignment between engineering education and engineering work. The National Academy of Engineering confirmed that "the disconnect between the system of engineering education and the practice of engineering appears to be accelerating" [2]. Wulff points out that many graduates enter the workforce ill-equipped for the complex interactions, across many disciplines, of real-world engineered systems [3]. The Royal Academy of Engineering concluded that work experience is a "primary factor in the recruitment policies of the great majority of companies and is highly influential in determining the selection of job applicants for interview" [4]. The need for gaining practical experience in the field during their studies is therefore very important for engineering students. "This perception is shared by students themselves, since the graduate focus groups expressed concern about limited and unrealistic project work they had experienced during their degree courses" [4]. More recently the survey of the Institution of Engineering and Technology showed

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that 39% of companies see the shortfalls in the lack of practical experience among graduates [5].

In 1989 the Velvet Revolution in Prague started dramatic changes in the engineering industry of the Czech Republic as well as in other countries of the former Soviet Union. As a consequence of tough international competition many of the established companies in the region went bankrupt as they could not rival the technologies and productivity of their competitors. The majority of the surviving companies stayed on the market thanks to their unique knowhow. For students of Machine Design this means that the engineering companies in the region are therefore reluctant to share their knowhow in order to educate a new generation of design engineers. However, the situation will get better over time as international companies enter the market. In the meantime it is important to provide real applications to students of Machine Design within the learning process as the study of Machine Design has been isolated from praxis in engineering companies and the competitiveness of graduates has been reduced [6].

The Faculty of Mechanical Engineering (FME) at the University of West Bohemia was unable to provide real projects to students as it had no archive of real projects. This was also a problem for academics as they could not demonstrate the taught principles on real applications. Therefore a new concept of electronic learning materials for Machine Design was developed as a part of the solution to this issue to provide a knowledge base for both academics and students at FME. The intention was to deliver real and complex tasks to students of Machine Design as "the prevalence of low-level task contributes to students' lack of understanding of content and process and poor attitudes toward learning and schooling" [7]. Attention was paid to "emphasize design (system) thinking, where students learn creative thinking and open-ended problem-solving, but always within the context of design's close connection with manufacturing (i.e. 'if you can't build it, you can't use or sell it')" [8], as understanding the connection between mechanical design and manufacturing processes is essential for all Machine Design graduates.

The new learning materials were designed to exploit the advantages of modern information technologies. The integration of effective technology into the learning process could enhance the learning process and "enable learners to process complex material more easily" [9]. Engineering content is necessarily visually intensive. Strong visuals separate engineering from other disciplines that may be more suited to strictly audio content [10]. Therefore the new electronic learning materials are based on interactive CAE models supplemented by additional illustrative information.

This paper presents new electronic learning materials as a part of the teaching process enhancement made by FME as a part of the solution to this issue.

2. Methodology

The conventional way of learning Machine Design is depicted in Fig. 1. Students work through several subjects to acquire the required engineering knowledge. Sometimes the knowledge they have acquired is then required in other subjects (subjects 3 and 5 in Fig. 1), while at other times they will need the knowledge in project-based subjects. Project-based subjects are often placed in the fourth and fifth year of their studies. That means they do not need the knowledge they have learned in the first year for another three or four years of their studies. The problem is not only the fact that they forget most of the knowledge during these years, but this way it is also almost impossible for students to see the connections between subjects. Therefore this learning approach could be called "learning without context".

The electronic learning materials focusing on real design projects allow students to study "in context". This means the students would study the design

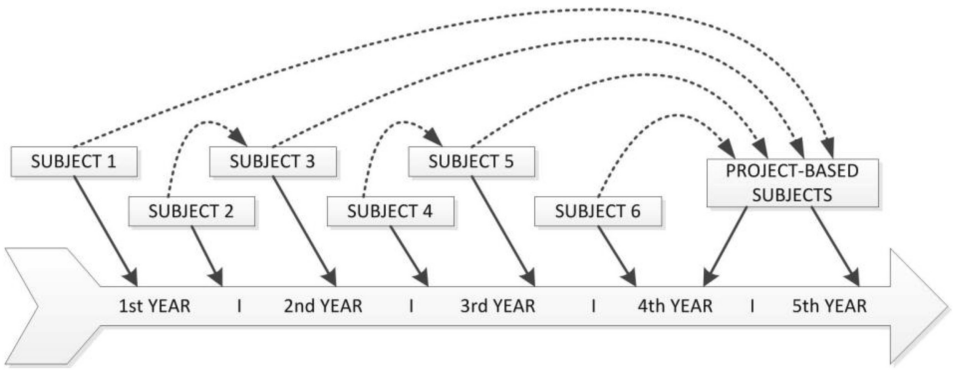

Fig. 1. Learning without context—knowledge acquisition and application.

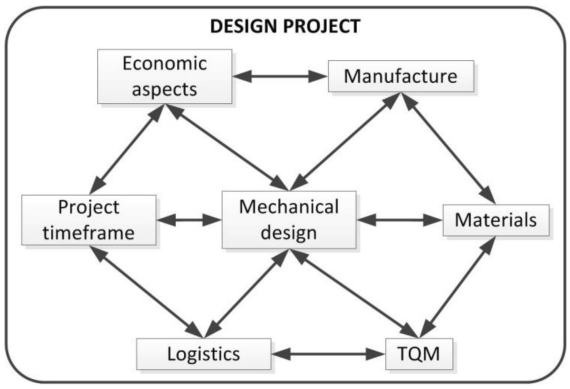

Fig. 2. Learning in context.

project to see its different aspects and connections. They would also be able to practise the knowledge acquired in different subjects. This learning approach could be called "learning in context".

The electronic learning materials were not created to replace the conventional way of learning Machine Design. They are meant to support and enrich the learning process at FME. This way mainly the bright students would be able to see the connections between different subjects even in the early stages of their studies.

3. Competencies required by Machine Design graduates

Firstly, the competencies required by Machine Design graduates had to be defined. Competencies required by Engineers can be defined as the stipulated engineering education outcomes. European-stipulated outcomes are defined by the European Network for Accreditation of Engineering Education:

- Knowledge and Understanding.
- Engineering Analysis.
- Engineering Design.
- Investigations.
- Engineering Practice.
- Transferable Skills.
  [11].

Alternatively, the Accreditation Board for Engineering and Technology define the requirements for graduates as follows:

- an ability to apply knowledge of mathematics, science, and engineering;
- an ability to design and conduct experiments, as well as to analyze and interpret data;
- an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability;
- an ability to function on multidisciplinary teams;
- an ability to identify, formulate, and solve engineering problems;
- an understanding of professional and ethical responsibility;
  [12].

Although the competencies required by engineers have been recently discussed, little attention has been paid to investigating the competencies from the Machine Design point of view. Based on the authors' sixteen years of experience in teaching design engineers, the following competencies have to be taken into consideration in the Machine Design field:

- an ability to communicate in foreign languages;
- an ability to use Computer-Aided Engineering (CAE) software;
- a knowledge of the mechanical design process;
- a knowledge of manufacturing processes;
- a knowledge of economic aspects of production;
- experience with real projects and applications;
- technical creativity;
- an ability to express their thoughts unequivocally;
- an ability to analyze and formulate technical problems.

These are the most important competencies for design engineers according to the authors' experience in the field. These competencies cannot be gained by learning theory only. It is necessary to work on real applications to gain these competencies, therefore the electronic learning materials are focused on providing real design projects to students of Machine Design.

4. Electronic learning materials

Design projects produced by local engineering companies were used as a basis for the electronic learning materials. The design projects were reworked by academics at FME into a form suitable for learning purposes. Each tool and machine was fully described and basic facts and principles related to it were explained.

4.1 Structure of electronic learning materials

Design projects are delivered to students in the form of PDF files. Every PDF file contains interactive CAE models imported from major CAE systems. The CAE models form the most important part of the electronic learning materials as they offer valuable engineering know-how. CAE models are therefore a great resource of information regarding the product structure and components' functions, but

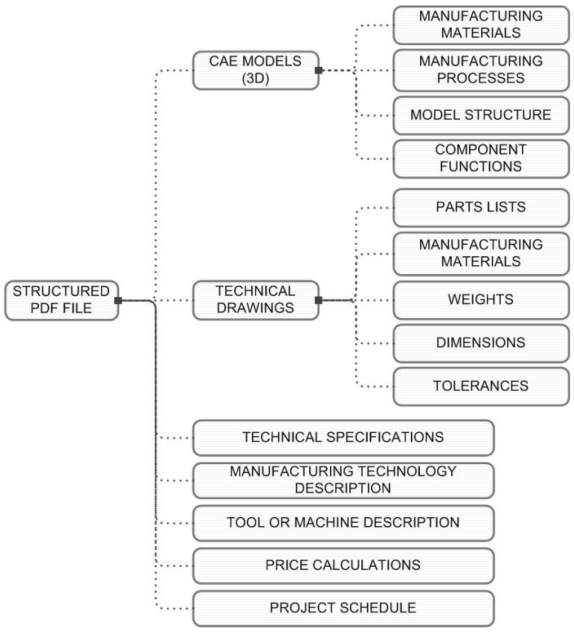

Fig. 3. The structure of the PDF file containing the design project.

they have to be supplemented with additional information regarding the function of the tool, economic aspects of production and manufacturing processes. The additional information is integrated into a single PDF file together with CAE models and technical drawings. The structure of the PDF file is depicted in Fig. 3.

Figure 3 shows the structured PDF file containing the CAE models, technical drawings and additional information related to the design project. Information regarding the model structure, manufacturing materials and processes or component functions is inserted in the CAE models. Bills of material, weights, dimensions and tolerances can be found in the technical drawings. Additional information regarding technical specifications, project schedule, machine description and so on is provided to fully describe each design project.

4.2 Form and content of electronic learning materials

4.2.1 Tool description

This part of the learning materials introduces the tool or machine and describes the important components, principles and conditions related to the design project. More importantly, it provides information necessary to understand the function of the tool and its components and therefore it is crucial for giving the students an insight into the design project. A tool description sample page is depicted in Fig. 4.

The sample page describes the sensors of an ultrasonic welding tool. It shows important information regarding the inductive sensors. Text information is supplemented with images of the tool and the sensors so as to be clearly comprehensible.

4.2.2 Interactive CAE models

CAE models provide a great source of mechanical engineering know-how. CAE Models converted to the PDF format are easy to work with. One can rotate it, create cross sections, make some components transparent or invisible and explore the tool or machine. There are a lot of parameters regarding the tool or machine and its components which one might need to know such as weights, materials, part numbers or positions of components in the assembly. One can find the information in technical drawings, but it is quite inconvenient to look in the technical drawings and search for it. Therefore these parameters are implemented into the CAE model and it is possible to view them just by selecting the component. Fig. 5 shows the CAE model of a hydraulic press.

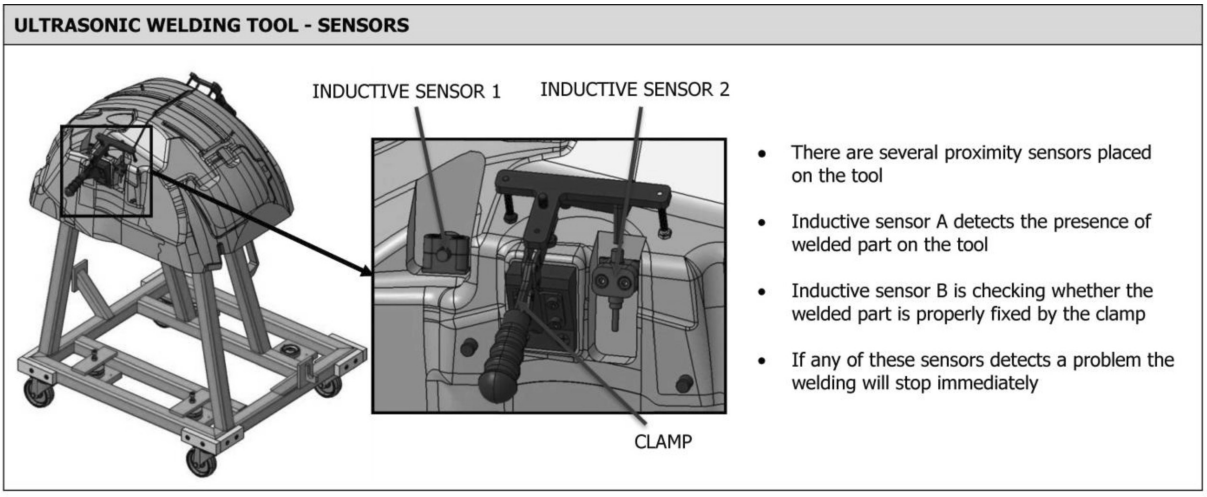

Fig. 4. Tool description sample page.

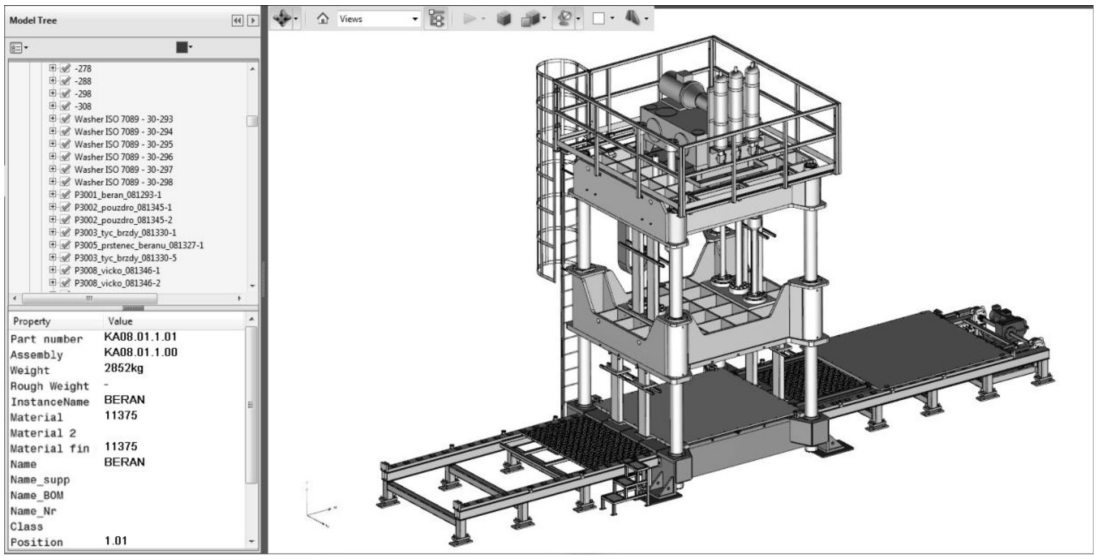

Fig. 5. CAE model of hydraulic press in the PDF file.

In the upper left corner of Fig. 5 the Model Tree is displayed. The Model Tree shows the structure of the tool. The CAE model is displayed in the graphic window. In the lower left corner the model parameters of the selected component are displayed. It is possible to see a component's parameters just by selecting the particular component. The tray for manipulating the model is located in the upper section of Fig. 5.

4.2.2.1 3DPDF Software requirements

All the content of the structured PDF file can be viewed by any PDF reader application such as Adobe Reader, Foxit Reader, Sumatra PDF or Nitro PDF Reader with one exception regarding the interactive CAE models. These are currently supported only by products of Adobe (Adobe Reader v9 and above, Adobe Acrobat v9 and above). Since Adobe Reader can be found or installed on any computer, is available for multiple operating systems and is offered free of charge, this compatibility issue is a matter of no importance. There is also no need to install any additional add-ons in order to explore interactive CAE models using Adobe Reader.

4.2.3 Technical specifications

Definition of technical specifications is the first phase of the mechanical design process. The form of technical specifications has to be unambiguous, clearly arranged, and multilingual. All requirements and conditions related to the project have to be included in the technical specifications to avoid mistakes and misunderstandings in the next phases of the design project. An example of the form of technical specifications used in the learning materials is shown in Fig. 6.

The first column contains the row numbers. The

Poz.	**Název** / Benennung / *Description*	**Typ - Poznámky** / Ausführung - Bemerkung / *Type - Remark*						
12	**Horký olej** / Thermalöl / *Thermal oil*	**ANO** / JA / *YES*				**Okruh: 1ks v jedné polovině**		
		X	**Díry** / Bohrungen / *Holes* [Ø]	18mm		Kreislauf: 1 Stück je Werkzeughälfte *Circuit: 1 part of mold half*		
		Rozměr připojení / Anschlußgröße / *connect. Dimension* **1 Palec** / Zoll / *Inch*				x	vnitřní / innen /*inner*	
							vnější / außen / *outer*	
		Vzdálenost / Abstand / *Distance*				80 mm		
		Spojení / Kupplung / *Connection:* Walter 11-019-2-WR53310-AAA						
13	**Izolace** / Isolierung / *Insulation*	**Material:**	Promassal		X	**horní** /oben / *upper*	20mm	
		Délka / länge / *length*			X	**spodní** /unten / *lower*	20mm	
		Šířka / breite / *width*			X	**boční** / seitlich / *side*	10mm	
14	**Konstrukce nástrojů** / Aufbau des Werkzeugs / *Structure of tool*	**Ocelová deska** / Stahlschonplatte / *Steel plate*						10mm
		Izolace / Isolierung / *Isolation*						20mm
		Celková výška / Gesamtbauhöhe / *Overall height*						min. 620mm
		Horní nástroj / Oberform / *Upper tool*						-
		Spodní nástroj / Unterform / *Lower tool*						-
		Izolace / Isolierung / *Isolation*						20mm
		Ocelová deska / Stahlschonplatte / *Steel plate*						10mm

Fig. 6. Example of technical specifications.

second column contains the row titles and in the third column the requirements and conditions related to the second column are clearly defined and annotated.

5. Contribution to students, academics and learning process

The main purpose of the electronic learning materials is to support the education process by providing the engineering know-how from industry to students and academics. Electronic learning materials are based on interactive CAE models combined with supplemental information and will be delivered to students in structured PDF files. By exporting CAE models to PDF format students are able to open the CAE models on any computer regardless of the installed specialized software, its policies and licenses. This means that the electronic learning materials can be used for many purposes such as students' assignments, theses, for their individual work or project-based teamwork.

Each design project can be easily modified by altering the technical specifications for the purpose of creating topics for students' theses or projects. Thus, all the topics would be based on real design projects so that students would be able to work on real design projects even without the involvement of engineering companies. Students would be able to study the original design project, learn from it and then they would apply their knowledge when working on their own project. In this way, students would create their own tools or machines similar to those made by local engineering companies. Additionally, learning materials will be available to academics at FME. They would be incorporated into different subjects, for example:

- *Engineering design using unconventional materials*—In this subject the technology of injection molding, molding machines and design of injection molds is taught. In lectures the CAE models of injection molds would serve to demonstrate basic principles of injection molding and mold design. During the tutorial students design their own simple injection molds. Electronic learning materials contain several CAE models of real injection molds. Students would be able to design complex injection molds similar to real injection molds.
- *Numerical Calculations in CAD*—In this subject the Finite Element Method (FEM) is taught. This method serves to solve complex elasticity and structural problems. Students would benefit by obtaining CAE models of real machines (e.g. a hydraulic press) in order to perform a structural analysis on them. In this way, students would be able to modify and optimize components of the machine in order to increase stiffness or reduce production costs.

Electronic learning materials cover the following fields of Machine Design: acoustic parts, casting and forging, injection molding, sheet metals, milling machines, lathes, hydraulic presses and tire presses.

The electronic learning materials have not been created to replace the conventional way of learning Machine Design. They are meant to support and enrich the learning process at FME. They provide a way for bright students to see the connections between different subjects even in the early stages of their studies. Therefore they cannot be objectively compared with the traditional way of learning Machine Design. The design projects can be used for supporting the different parts of the teaching process at FME. They provide an archive of technical knowledge to both students and academics at FME and can be used to enhance different subjects at FME.

6. Conclusion and future work

Universities are required to cooperate with local engineering companies in order to produce competent graduates. However, there is still a lack of opportunities in the Czech Republic for students of Machine Design to acquire valuable experience in the field during their studies. The Faculty of Mechanical Engineering at the University of West Bohemia has been concerned with this issue for many years. FME has developed electronic learning materials for Machine Design to improve the teaching process and bring engineering know-how to the faculty. Electronic learning materials have been created in cooperation with local engineering companies and will be delivered to students in an interactive form based on 3D CAE models. The purpose of this paper is to explain the electronic learning materials and their contribution. At first the competencies required by Machine Design graduates were defined. Interactive project-based electronic learning materials were introduced while focusing on the 3D CAE models imported to the structured PDF file and accompanied by additional related information. Furthermore, important parts of the electronic learning materials were described along with their benefits to academics and students of Machine Design.

In the future, it would be appropriate to carry out a questionnaire to verify the acceptance of the learning materials. It is also important to identify the drawbacks and technical difficulties involved in order to eliminate them. Afterwards, all the electronic learning materials will be made available to

students at FME through the courseware of the University of West Bohemia.

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