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Development of Simulation Based Machine Design Course

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Abstract

While the traditional product design method emphasizes the structure and the documentation of the design work, simulation based design can add more value to the design process by using for example multi-body, thermal or strength analysis. These tools are traditionally be used to replace physical prototypes and the utilization of these tools in the concept design phase has been limited.

Traditionally product design courses have been divided into courses teaching theory and processes of machine design, and courses teaching the computer aided design and simulation tools. With a new master level course, Machine Design, both approaches can be learned at the same time. During the course, a freely selected one degree-of-freedom mechanism based on existing machine is modelled, studied and optimized using Siemens NX and PTC Mathcad. Emphasis is on the iterative design process and on testing different structures, sizes and materials in the chosen case machine. The course follows systematic product design process, starting from defining requirement list, functional block diagram and product structure. Simulations are used to test different solutions and narrow the design choices. Machine elements are chosen for the final concept and the outcome is reflected on.

The course has been run for two years. The annual amount of multinational students is about 100. The course feedback has been positive – the students appreciate the possibility to create a machine from the scratch and to learn use and apply simulation tools in the process. The course development is an ongoing process and the further steps include the integration of the product data lifecycle management system. This paper describes students' perceptions of this course's approach to product design and how it has effected the development of the course. The focus of the design assignment will be moved towards real engineering problem solving task to better demonstrate the benefits of simulation based design.

Keywords: FEM, MBS, mechanical engineering, course design

1 Introduction

The digitalization of the industry, the increasing complexity of the products and amount of product related information set new challenges for the education of the future engineers. To outperform competitors and to provide cost-effective products, simulation based design method can be used. Simulation based design, also called as simulation driven product development, is a broadly accepted product development approach in the semiconductor, aerospace, and automotive industries. Currently also other fields, like biomechanics, are interested in this method. (Bossak, 1998; Ferretti, Magnani, & Rocco, 2004; Marchal & Dhanasekharan, 2007; Ong, Hicks, & Delp, 2015) While the traditional product design method emphasizes the structure and the documentation of the design work, simulation based design can add more value to the design process by using for example multi-body, thermal or strength analysis. The simulation based design process highlights the iterative nature of the design (Figure 1).

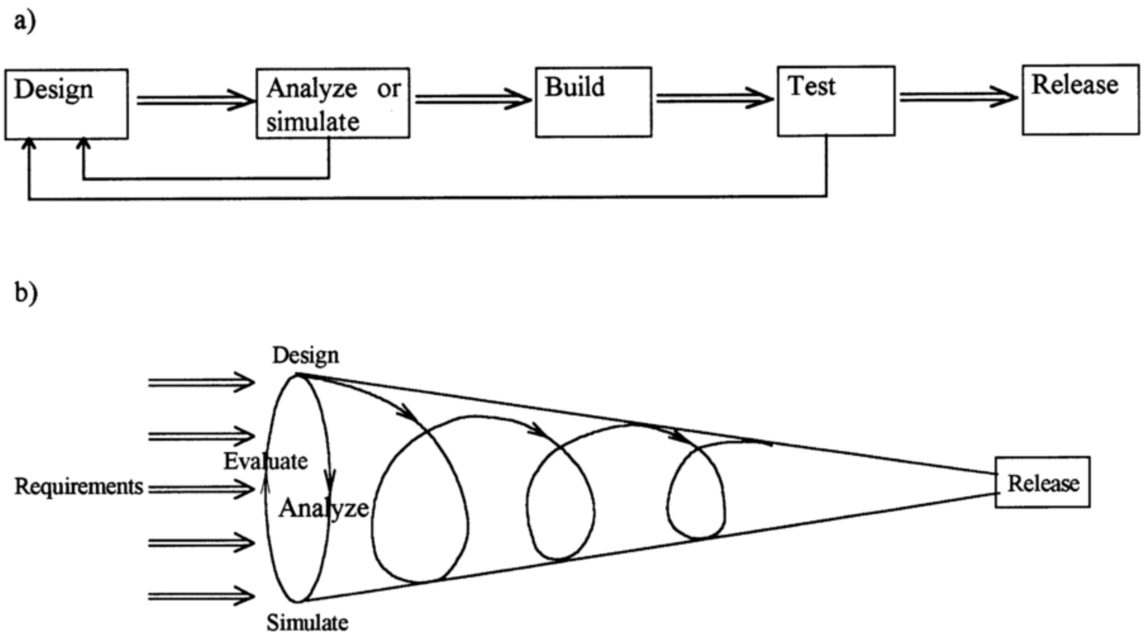

Figure 1. Two approaches to simulation based design: a) planar and b) spatial (Bossak, 1998)**.**

Simulations should be integrated in the design process from the beginning of the product development so that designers will have a better understanding how the product works and how design changes can alter the behaviour of the entire product (Vanhatalo, Saaski, & Riitahuhta, 2006). Using analysis when the complete product is assembled serves mostly as a check but not as proactive support for design. Simulations are specifically important for the design of multi-disciplinary systems where components in different disciplines are tightly coupled to achieve optimal system performance (Sinha, Paredis, Liang, & Khosla, 2001).

The increasing computation power of computers enables more effective use of simulation and optimization tools in different phases of engineering design. Simulation tools can be used in the concept design phase to find the optimal solution. The same tools can reduce the number of required physical prototypes and thus both hasten design process and save recourses (Merkel & Schumacher, 2004). The ongoing development of CAD (Computer Aided Design) and CAE (Computer Aided Engineering) tools enables efficient utilization of simulation based design approach. Nowadays several commercial software packages, such as Catia, Creo, Inventor, Solid Edge, Solidworks and NX, allow the design and simulation in the same environment. This enables utilization of iterative design cycle, where different concepts can be tested and optimized in the same software by using behavioural modelling (Sinha, Paredis, & Khosla, 2000).

Previously the teaching of design methods and computer aided tools were separated. There were own courses for the theory of machine design process, where simulation tools are seen as replacement of physical prototypes, and thus utilization of these tools often come after or during detail design phase. Own courses offered were for CAD and utilization of MBS (Multi-Body Simulation) and FEM (Finite Element Method). To demonstrate the possibilities of simulation based design, the courses about design theory and simulation tools should be integrated to enable students to get the theory knowledge as well as practical tool skillsets.

This paper presents results from two iteration cycles of a new Machine Design course. This course introduces simulation based design approach to the master level students. Students' perceptions of this course are described as well as their approach to product design and how it has effected the development of the course.

2 Machine Design Course

2.1 Background

The *Machine Design* course is a 5 ECTS, a 7 week single period course aimed for the first year of master studies in the mechanical engineering degree programme. Annually about 100 students takes this course, including exchange students. The course was first time in the curriculum in fall 2016.

The learning outcomes of the course are:

- To be able to recognize basic elements, concepts and methods of machine design.
- To know and utilize computer aided tools in mechanical engineering tasks.

The aim of the course is to introduce simulation based design approach to mechanical engineering students. The students are already familiar with traditional design methods (Pahl, Beitz, Feldhusen, & Grote, 1996; Ulrich & Eppinger, 2011) and CAD in general. This course presents simulation tools, like mechanism and strength analyses, to the students. Parallel to this course, a 10 ECTS and two period *Machine Design Project* course is offered, and it is assumed that most students take both courses at the same time. This enables the utilization of acquired skills in a context of a practical project work.

The backbone of the course is a continuous exercise work in groups of four persons, during which a one degree of freedom mechanism is studied and redesigned in four phases (Figure 2). The students start with the *preliminary design*, where the requirements and functionalities of the product are defined. Then *mechanism analysis* using multi-body simulations (MBS) are carried out to study the behaviour of the mechanism and to define the connections and joint types. Next, the mechanism analysis results are used in the *strength analysis* using finite element method (FEM) to test that mechanism's parts can withstand the loads and to further shape the geometries of the parts. In the *detailed design* phase, based on the requirements and simulation results, machine elements (such as bearings, actuators) are selected and detailed design of the machine is executed. Each of the phase ends with written report, which are graded with a scale from 0 (fail) to 5 (excellent). In the weekly reports, students also reflect on what they have learned during the exercise.

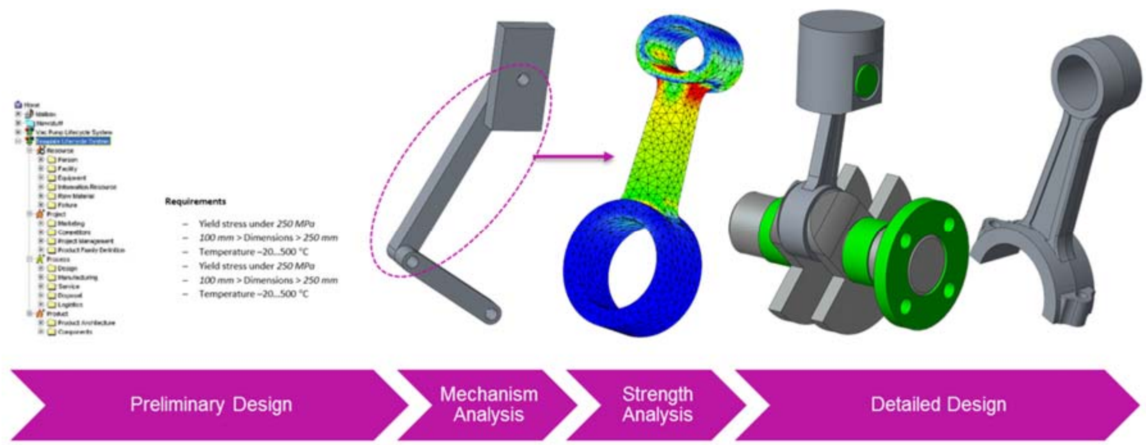

Figure 2. The phases of the group work.

The course contains weekly two lectures (á 2 h) and two exercise sessions (á 4 h) in the computer class to support the group work. Besides supporting the group work, lectures can include invited speakers from the industry to motivate the students and to show them how the same tools and methods are used in the companies. Participation in the lectures and in the exercise sessions is voluntary and thus not graded.

2.2 First iteration

The course was offered for the first time in fall 2016. The course was five weeks long and contained the same phases as presented in Figure 2. All phases lasted one week, except for the last one, that was two week long. During the preliminary design phase, the course staff assigned groups based on the enrolment form. In the form, students were asked to self-assess their skills in CAD, different simulations and design methods. The groups were then formed from students with different skillsets.

Besides learning design methods, students could learn to utilize different software packages. During the first iteration, PTC Creo and Mathcad were used for the mechanism analysis, and Siemens NX for the strength analysis and for the detailed design phases. The reason for two different software packages was first to courage students to make simplified models for the mechanism analysis phase and second to show the similarities and differences in the commercial design tools.

2.3 Second iteration

The course was held second time in fall 2017. Due to changes in the curriculum, the course was now six weeks long. This time group enrolment was different – the students could form the groups themselves. The course structure remained the same, but schedule was adjusted. The extra week was added to the beginning to have more time with the preliminary design phase.

During this iteration, a simplified skeleton design approach was introduced (Mun, Hwang, & Han, 2009). In the detailed design phase, students were asked to create a moving skeleton to demonstrate the selected mechanism. In the skeleton design, a frame assembly or part is created and all added parts are attached to the skeleton (Figure 3). The parts are depended on the geometries and dimensions of the skeleton, but not for each other. This enables easy interchangeability in assemblies.

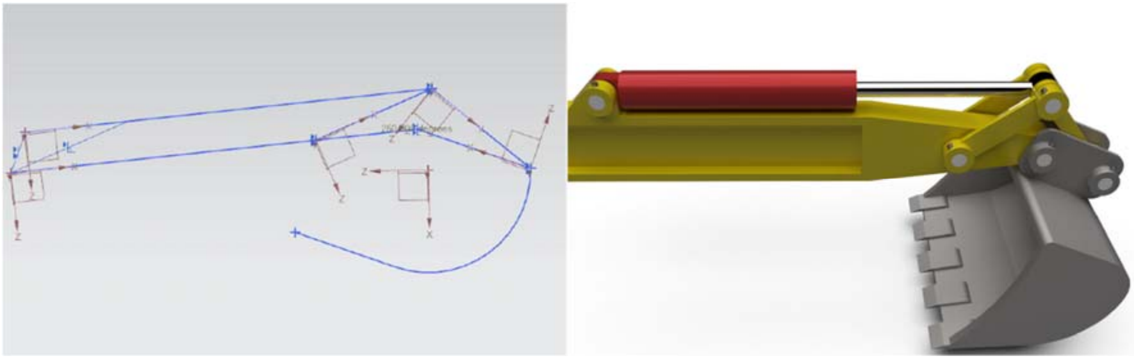

Figure 3. Excavator bucket mechanism: skeleton on left, final design on right.

Due to the implementation of skeleton modelling, all the design and simulation tasks were done with Siemens NX. PTC Mathcad was used as a calculation software for various tasks, for example to calculate bearing lifetime.

3 Results

To collect background information and the perceptions of the students about design methods used during the course, two online surveys were carried out. The first one was in the first week of the course, where background information, including previous experience with design methods and simulation tools, were collected. The second one was after the course, when students were ask to evaluate how their skills had developed and how the group performed. In this chapter, combined survey results from first (1^{st}, N=91) and second (2^{nd}, N=86) course iteration round are presented.

Students' skills in different tools/method and change during the course are presented in Figure 4. In the graph, the results from the start survey is presented with the darker colour and the change during the course with the lighter.

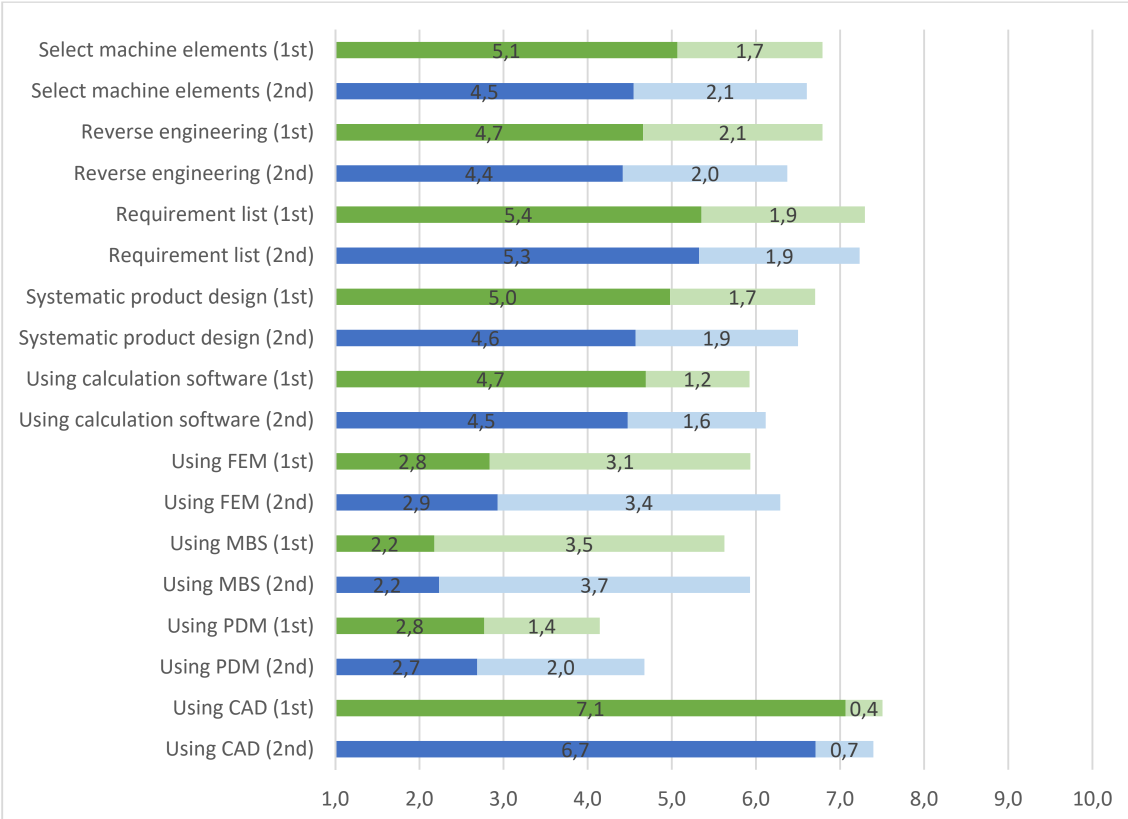

Figure 4. Self-assessed skills and their progression during the course iterations.

The group formation method and group working was surveyed, and results can be seen in Figure 5. The way how groups was formed was different in the iterations. In the 1st iteration, groups were assigned by the teacher using student's self-assessment of skills presented in Figure 4. In the 2nd iteration, the students were allowed to form groups themselves.

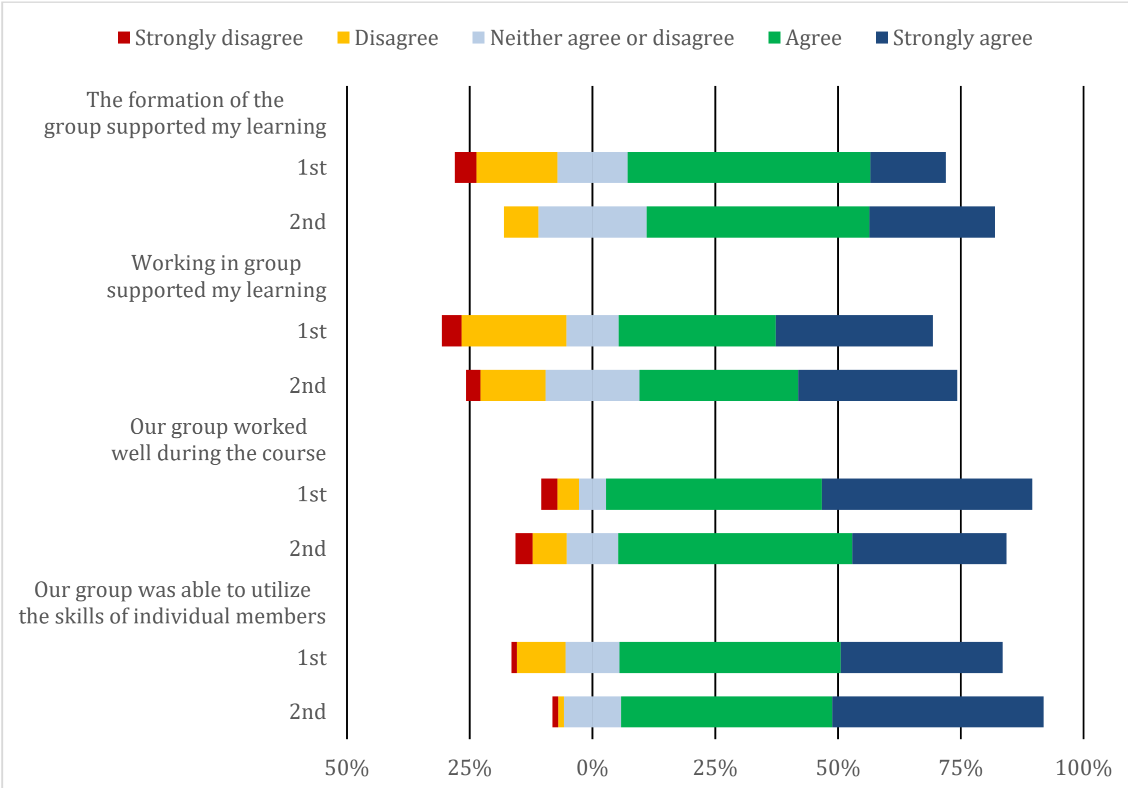

Figure 5. Students' perception of group formation during different iterations.

The student groups were slightly more learning oriented (average value of 6.1 in 1st and 6.2 in 2nd iteration) than grade oriented. The answer distribution from grade oriented (1) to learning oriented (10) is presented in Figure 6.

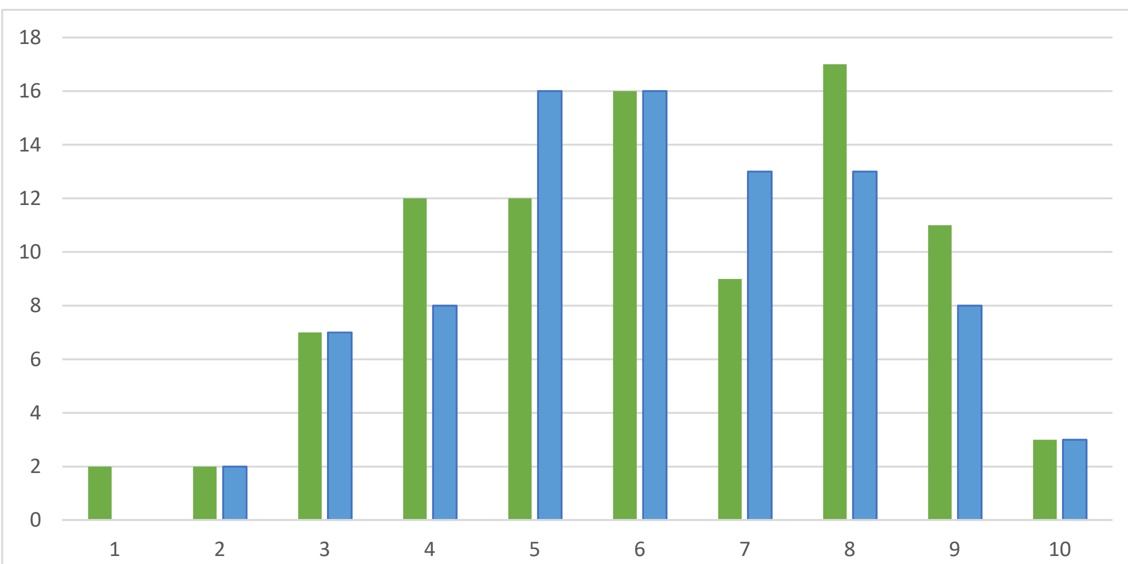

Figure 6. The student group attitude towards grade (1) and learning (10) oriented approach. 1st iteration in green and 2nd in blue.

The overall student feedback of the course is presented in Table 1. The scale was from 1 to 5, where the higher number is the better (except in "Workload", were 3 was optimal). Students would recommend this course (91.2% in 1st and 94.2% in 2nd iteration) to fellow students.

Table 1. Students' general feedback about the course.

Year	N	Overall assessment	Teaching methods	Own study effort	Workload	Benefit
2016	42	3,4	3,5	3,6	3,3	4,0
2017	49	3,8	3,7	3,8	3,1	4,3
Change	+7	+0,4	+0,2	+0,2	-0,2	+0,3

The participation in lectures or exercise sessions were voluntary. On average, in the first iteration a student attended in 59.1% of lectures and 66.8% of exercise sessions. In the second iteration, the values were 48.8% and 66.0% respectively.

4 Discussion

In the first year on the master programme, the skillset of the students related to applying simulation based design is rather low. This indicates that these tools are not introduced to them in previous studies. The students have better skills in the theory of the machine design process and in CAD tools. During the course, the skill levels rise in all of the fields. The biggest progress was in utilization of simulation tools (FEM and MBS). By average, the students weren't previously familiar with simulation tools, so skill progress in these field was excepted. The skills related to product design (requirement lists, selecting machine elements, systematic product design, PDM) also progressed. All of these skills, except PDM, were already high. The rise of PDM related skill was a result from a couple of lectures, because the implementation of PDM system was still in the process. The smallest skill change was in the usage of CAD. CAD tools were used during the group work to create the needed geometry for simulation models.

To better support the mindset of simulation based design, it will be beneficial if simulation tools and methods (MBS and FEM) where introduced to the students in the bachelor level. This could be done by including some computer exercises in the basic engineering courses, like using MBS to analyse kinematics of a system in dynamics course, or to use FEM to compare hand calculations in the strength of materials course.

The group formation method had a slight effect on how the group work supported the learning and how the skillsets of the individual members were utilized – students seem to prefer forming groups themselves, although group may work slight worse in this case. The overall differences between teacher and self formed groups were small. The student groups were both grade and learning oriented.

The developing of the course continues. The group work topic will be changed from analysing an existing machine to designing a machine for predefined purpose. This way the simulations (multi-body and strength) can have a bigger impact to the outcome, and students can use tools to test different mechanisms and structures. The whole design process and its documentation will be integrated to PDM system (Teamcenter) to demonstrate the actual design environment in the industry.

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