Abstract— In the field of mechanical engineering, computer aided tools are part of everyday life. Increased quality standards, new production methods and pace of product development drives the education at the universities. This paper focuses on CAD and CAE teaching at Aalto University School of Engineering. The learning environment in the Department of Engineering Design and Production contains classrooms, software and web-services. Five different CAD/CAE-related courses from both bachelor’s and master’s degree programme are presented. Common teaching methods include weekly practical exercises, supporting lectures and open-topic final works. During the exercises, students will learn skills to create geometric representation and to analyze them, and in the lectures, methods to create and analyze are presented. Main learning will happen while applying learned skills to problem solving in projects. This kind of arrangement has got positive feedback from the students and work to develop the courses in this path will continue.

I. INTRODUCTION

For today’s mechanical engineers, CAD (Computer Aided Design) is a ubiquitous tool. 2D technical drawing has been a standard way to document and communicate designs. Increased quality demands and new manufacturing techniques, such as 3D printing or five-axis milling, are based on 3D models of parts and components. Even if the final output of the design work would be technical drawings, the actual design is mostly created using 3D CAD software.

In the mechanical engineering field, CAE (Computer Aided Engineering) tools are used to study and inspect models created by CAD applications. CAE includes geometry analyses, such as Finite Element Analysis (FEA) or Multi-Body Simulations (MBS), and production analyses, such as casting and molding simulations.

There has been a considerable interest on development of CAD education at universities the world over, see e.g. [1], [2] and [3], as well in industry [4]. Common interest is that education must build both expertise and working life skills. Ye et al [5] list four important requirements for CAD education: the ability to formulate the engineering problems, the ability to use a computer in solving engineering problems, a good understanding of the design process and PLM technologies and, most importantly, practice.

According to its strategy, Aalto University was established to strengthen the Finnish innovation system by way of integrating expertise in science and technology, business and economics as well as art and design. The university will build its operations on top-quality research and research-based education. In a learning-centered culture, students are guided towards a strong commitment to their studies and to taking responsibility for their own development.

CAD and CAE teaching at Aalto University is mainly focused to School of Engineering. Computer aided tools are taught and used in mechanical engineering, in civil engineering, in applied mechanics and in energy technology. This paper focuses on mechanical CAD and CAE teaching in the Department of Engineering Design and Production.

II. LEARNING ENVIRONMENT

Learning environment consists of classrooms, software and Internet based learning environments.

A. Classrooms

The Department of Engineering Design and Production provides two main teaching classrooms: CAE- and CAD-classroom. They are available for students during office hours (Mon-Fri 8 am to 8 pm). Students also have a possibility to use Maari-building, where several computer classes are available around a clock.

CAE classroom (Fig 1) has workstations for 24 students and for one teacher. Computers meet today’s requirements for CAD design, including large displays. In addition, a full screen projector connected to teacher’s computer exists. This space is the main teaching class for advanced CAD/CAE-courses.

Fig 1. The CAE classroom.

CAD class has workstations for 64 students. When needed, this room can be divided to two smaller spaces. Room is used mainly for basic CAD-courses and it also works as a general computer class for the department.

B. Software

To encourage students to test and experiment with different computer aided tools [6], a large selection of software is available in the teaching classes. Students have possibility to install some of the software to their home computers.

The primary software used in teaching is Creo, previously known as Pro/Engineer, by American company PTC. This integrated software package contains module for CAD, but
also modules for CAM (Computer Aided Manufacturing) and for FEA (Finite Element Analysis).

In the basic CAD-courses, primary software are Autodesk AutoCAD, PTC Creo and Siemens Solid Edge. In the advance level, Creo is mainly used. In CAE teaching, main software are PTC Creo and MSC Adams.

### TABLE I

<table>
<thead>
<tr>
<th>Available CAD/CAE Software</th>
<th>Name (Supplier)</th>
<th>In rooms</th>
<th>In teaching</th>
<th>Home use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abaqus (Dassault)</td>
<td>CAE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Adams (MSC)</td>
<td>CAE</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AutoCAD (Autodesk)</td>
<td>CAD, CAE</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Catia (Dassault)</td>
<td>CAE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Creo (PTC)</td>
<td>CAD, CAE</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>NX (Siemens)</td>
<td>CAE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Solid Edge (Siemens)</td>
<td>CAD, CAE</td>
<td>✔</td>
<td>✔</td>
</tr>
<tr>
<td></td>
<td>Solid Works (Dassault)</td>
<td>CAD, CAE</td>
<td>✔</td>
<td>✔</td>
</tr>
</tbody>
</table>

C. Internet Environments

Aalto University currently offers four main Internet services for teaching. Noppa for course home pages and to distribute teaching material, WebOodi for course enrolment and managing of study programme, Optima for returning assignments and for online discussions and Moodle for supporting group work, discussions, returning assignments and to distribute material.

In the autumn 2015, Noppa, Optima and Moodle will be united with one single virtual learning environment, AVLE (Aalto Virtual Learning Environment). Pioneer courses will use AVLE in the beginning of year 2015.

Besides Internet browser based services, Aalto offers virtual home directory for all students, where their can store school related data.

To support teaching, returning folders for each course exist. Those folders are used to return larger quantity of data, e.g. CAD-assemblies or simulation results.

### III. COURSES

Aalto University started a renewed bachelor’s degree programme in the academic year 2013. However, at the same time older bachelor’s degree programme (2005) co-exists. This leads to situation where several courses for different study programmes are offered parallel.

The master’s degree programme will be renewed at the academic year 2016. CAD/CAE-related courses in the new master’s programme are still under development.

Study path offered by the Department of Engineering Design and Production is presented in Fig 2 and courses listed in Table II. The academic year at Aalto is divided to five periods of seven weeks each; two in the autumn (I-II) and three in the spring (III-V).

---

### TABLE II

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
<th>Level and Programme</th>
<th>Periods</th>
<th>Students yearly</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD Basic Course</td>
<td>5</td>
<td>3rd year Bachelor, 1st year Master (2005)</td>
<td>I-II, III-IV</td>
<td>110</td>
</tr>
<tr>
<td>CAD Advance Course</td>
<td>6</td>
<td>1st and 2nd year Master (2005)</td>
<td>I-V</td>
<td>50</td>
</tr>
<tr>
<td>CAE Project</td>
<td>3</td>
<td>1st year Master (2005)</td>
<td>III-IV</td>
<td>15</td>
</tr>
<tr>
<td>Computer Aided Tools in Engineering</td>
<td>5</td>
<td>1st year Bachelor (2013)</td>
<td>IV-V</td>
<td>290</td>
</tr>
</tbody>
</table>

A. **Machine Design Basics A**

This course is a general orientation course to the world of mechanical engineering. It is aimed to the 1st year students and the teaching language is Finnish. The course is obligatory to all students in the older (2005) mechanical engineering bachelor’s degree programme.

Learning outcomes of the course are

- to identify and understand basic concepts in machine construction
- to identify and understand methods for technical documentation.

First part of the course consists of lectures and exercises about different fields in mechanical engineering, such as production technology, material science etc. The second part concentrates on drawing standards and how to use 2D and 3D CAD to make drawings or design a part.

During the course students produce various CAD models; in the autumn simple 2D drawings and in the spring 2D drawings based on 3D geometry. The drawings are graded based on the ISO standard and students are graded from 0 to 5, where 0 is fail and 5 is excellent.

B. **Computer Aided Design Basic Course**

This course is, despite its name, more advanced CAD course. This is an obligatory course to all students in the machine design major or minor in the previous (2005) bachelor’s degree programme. It is recommended to students in 3rd year in bachelor’s degree programme or 1st year in master’s degree programme. It is also a part of the international master’s degree programme in mechanical engineering and thus teaching language is English. The course is offered twice a year: in the autumn and in the spring.

Learning outcomes for the course are

- modeling of basic features and extrusions
- parametric modeling, features and history trees
- assemblies and special applications like sheet metal and drafting
- ability to create design automates
- usage of Creo Parametric.

Course aims to give students ability to create parametric and scalable 3D CAD models (Fig 3). A lot of emphasis is put on to point out the ability to create CAD models that any other engineer can change or reuse. One objective is also to show what a modern CAD application can do, so students after graduation can use those skills to improve the usage of computer aided tools in their workplaces.
Fig 3. A parametric Lego brick model with four different variations.

Course consists of two lectures, ten weekly guided exercises and personal final project. First lecture is given in the beginning of the course as an introduction to parametric way of thinking and pointing out that one is not creating a CAD model to oneself, but to the others. The second lecture is given in the mid of the course. The personal project topic and requirements are published and guidance how to start design and modeling processes are given.

The majority of the learning takes place during the weekly exercises. There are ten four-hour-long exercises in the supervised exercise groups in the CAE class. The topics of the exercises vary from the basic material creating and editing methods to more advanced parameterization and scripting methods. For example, the fifth exercise is to create a scalable Lego brick, that user can control with three different parameters (length, width and height). Also special areas, like rendering and geometry optimization are covered. 80% of the exercises are obligatory and they are graded with pass/not pass. Exercise material is created by the course staff and given to the students in PDF format using Noppa. Primary CAD application is the Parametric module of PTC Creo.

Fig 4. Two variations of a tower crane.

The objective of the personal project is to create an assembly containing at least 15 different parts using the tools learned during the weekly exercises and methods learned during the lectures. This assembly should also be controlled with at least three different parameters. The topic is same for every student and it varies every semester. Topic is very general, so student needs to simplify initial design and concentrate to certain areas. Topics in the past include tower crane (Fig 4), SLR camera, barge, submarine, tractor and cherry picker. The variation of topics is wide, but the grading criterion, which is given when topic is published, is the same.

Personal project is graded from 0 to 5, where 0 is fail and 5 excellent. Personal project grade, if exercises and project are done on time, will also be the final grade for the course.

Course is aimed for the students in machine design major, but also students from other areas, like production technology, engineering materials or even from chemical technology, are welcome.

Feedback from the course has been collected using web-based questionnaire using only open questions.

C. Computer Aided Design Advance Course

This course aims to give a good overview about usage of different kind of computer aided tools. Besides more advanced CAD modelling methods, strength and motion analyses are covered. Teaching language is Finnish. This one academic year long course is an obligatory course in the old master’s programme (2005) in a voluntary computer aided design and simulation module. Other courses in the module cover topics of C-programming, mechanism design and simulation, and finite element analysis.

Learning outcomes are:

- knows computer aided tools used in product development
- overview of simulation tools such as Finite Element Analysis and Multi-Body Simulations
- skeleton and surface modeling
- project working using computer aided tools.

Autumn part of the course contains lecture series, lecture diary, weekly exercises and personal final work. A spring part is reserved for project work in groups of 3 to 5 persons.

Objective of the lecture series is to give an overview of usage of different computer aided tools or methods in industry and research. Lecturers are from Finnish industry and from the department. Topics include mechanical CAD, surface modeling, scripting, FEM, Product Data Management (PDM), company’s mechanical design environment, multi-body simulations, casting simulations, model automation and CAM. Student writes lecture diaries about lecture’s topic reflecting it to one’s past school or work tasks. Lectures also support weekly exercises and project work done in spring. Students are asked to give feedback and comments about
lectures in their diaries. This feedback is used when choosing future lecturers or topics. Diaries are graded pass/not pass.

Weekly computer exercises give basic knowledge to use more advanced modeling techniques in CAD such as using skeleton techniques when creating assemblies and using surface modeling tools to create complex shapes. They also cover simulation related topics such as mechanism simulations and finite element analysis. Weekly exercises (7 weeks) are arranged in the CAE classroom. Used software is PTC Creo, especially CAD and CAE-modules. Exercises are graded pass/not pass.

In personal final projects students can use skills learned during exercises to achieve pre-defined goal. The task is to model some familiar household device, such as blender, table fan or remote control. Students need to use skeleton and surface modeling methods during this project. Final work is only subtask that is graded during autumn semester using grading system 0-5, where 0 is fail and 5 excellent.

Spring semester in this course starts with presentation of project work topics. Students have also possibility to suggest own topics. Topics of the projects vary from reverse engineering, structural and thermal simulations to creating an advanced design automate. Project work groups contain 3 to 5 students. During the project works, groups also write task definition, mid-term and final reports. In the end of the spring semester, groups present their works in seminars.

Guidance of the project work teams is arranged by on-demand principle. When students need some help or want to discuss about their projects, they contact teachers. In the beginning of each project, a longer meeting with responsible teacher is organized to define the task based on student field of interest. The initial topic is open and can be clarified during the first meeting and task definition report phase.

Some of the project work topics are from the department related research or education. This motivates students, because their final work will be used somewhere and not forgotten after the course.

Cooperation with hydraulics research group has created several mechanism models and animations of different kind of valves, motors and pumps (Fig 5). These models can be used in the hydraulics field basic courses to get new students familiar with equipment used to create hydraulic systems.

In the field of mechatronics, a CAD part library and example assemblies of basic Lego Mindstorm package is created. These models can be used to test and simulate behavior of Lego-based robots in mechatronics courses.

During the semester 2013-2014 a group of virtual models of old mechanism models from 1850s were created in cooperation with the research group of history of industrialization [7]. Those old models are worn-out and some of them are broken, so they must be located in the closed showcases. One student group created demonstrating videos of those mechanisms-. This task also included measuring the old models and creating virtual mechanism model with a CAD application. One of the models can be seen in Fig 6.

Course final grade is an average of autumn’s personal work and spring’s group project. This way both student’s individual learning and group working skills are graded. Typically, the average of all students’ grades in autumn is lower than the average of project work grades. For example, in the academic year 2013-14 personal work average was 2.9 and project work average 4.0. This shows the benefits of working together to solve problems.

Course feedback is collected using feedback system provided by Aalto. The more detailed feedback of autumn part is collected in pursuance of lecture diaries. The method to collect feedback from project work in spring is under development.

D. CAE Project

CAE Project course is targeted to the students in international master’s degree programme (2005) and held in English. It is included in a module of digital design and manufacturing alongside courses about digital production, welding and casting. It is recommended to 1st year students in the master’s programme

Learning outcomes are

- knows the principles of modern CAE techniques
- awareness of different CAE techniques bring to the products life cycle
- working in groups with computer aided tools.

Course contains lecture series, lecture diaries, computer exercises and group project work.
Lecture series covers topics like good practices in CAD, basics of FEM, skeleton and surface technologies and management of product data. Lectures support students during their exercises and project work.

Topics of the CAE classroom exercises are skeleton modeling, surface techniques and creating simulations such as multi-body and finite element analysis. Exercise material is created by course staff and handed as pdf-files. Exercises are graded pass/not pass.

Main learning in the course takes place in project teams. Students are divided into groups of three persons. The task of the group is to demonstrate Simulation Based Design (SBD) method [8] using their own independently defined problem. Students must present three different concepts to solve their problem, e.g. lifting a box, closing a door or landing a plane (Fig 7). Out of three, one concept is chosen using multi-body simulations and other criterion. For the selected concept, finite element analyses are carried out to optimize its structure.

In the common part, basics of 2D and 3D modeling are presented. Students start with two-dimensional drawings using Autodesk AutoCAD and then continue to three-dimensional modeling using Siemens Solid Edge. In this way, all students in the school are familiar with modern geometry modeling software. Module contains lectures related to usage of the software and general application fields. Weekly exercises are carried out to learn how to use those CAD applications.

In the elective part, students can choose a software module based on their interest. In the spring 2014, elective applications were PTC Creo for students interested in mechanical engineering, Tekla Structures for students interested in civil engineering and ArcMap for students interested in survey and environmental engineering.

In the elective part, the Department of Engineering Design and Production is responsible for mechanical engineering CAD teaching module. The module contains lectures about software, engineering design practices and about later use of CAD models (e.g. production planning, simulation). Weekly exercises are carried out to learn the basics of modern mechanical engineering CAD application. The last exercise is longer than the first ones. There student will create a model of some basic machine element (Fig 8).

Project groups write a final report and present their case and methods in the end seminar. Project works are graded 0-5, where 0 is fail and 5 excellent. This will also be the final grade of the course.

E. Computer Aided Tools in Engineering

This course is part of the new bachelor’s degree programme (2013) at Aalto. It is an obligatory 1st year course to all students in the School of Engineering. This means about 290 students per year. School has three bachelor’s degree programmes: Energy and Environmental Engineering, Mechanical and Civil Engineering, and Build Environment. In this course, like in majority of the courses in the new bachelor’s degree programme, teaching language is Finnish.

Learning outcomes are

- knowing the basics of computer aided tools
- ability to uses computer aided tools to solve basic problems.

The course is divided into two parts: the common part, which all students take during the first period, and the elective part, where students choose one most interesting software module. During this course, students also write learning diaries.

Course feedback in last academic year was collected using a prototype of Aalto’s new feedback collecting system. Based on the feedback, participants gave a very good grade to the course in general and think that methods and tools learned in this course will be useful in the future. Negative feedback mostly concerned learning diaries used in this course. In the coming spring, learning diaries are removed and more emphasis is given on weekly exercises.

IV. DISCUSSION

Common nominator for the different CAD/CAE courses in the department is lecture series, weekly practical computer exercises and open-topic final works.

Lecture series have two main targets: to support students in their weekly exercises or project works, and to present different kind of computer aided tools [9] and their usage in the industry. Based on discussions and lecture diaries, students seem to value this kind of arrangement. In addition, students get confirmation that different tools and methods

Fig 7. A landing gear case. On top: three different concepts. On bottom: final optimized structure.

Fig 8. A rendered ball valve.
taught at university are used in the industry and thus help to motivate in their project works.

Weekly exercises are essential to get hands-on experience. Aim of these exercises is to teach both software usage, which is valued in the industry, and different kind of methods to create, modify and analyze geometries and products. Exercise material is created and developed by the staff members of the department. In this, perhaps a laborious, way study material can be targeted more precise to certain courses and topics.

Using open topics in the project works seems to motivate students. With well-defined guidance, students have the freedom to make their own version of a product they see in their everyday life. The topics are mostly based on complex system, e.g. tractor, allowing the students to focus on the areas they are most interested.

Open topic also seems to reduce the reusing/copying of other students’ models. In the last five years, only one plagiarism situation has happened.

Feedback from the CAD/CAE courses has mostly been positive. The course participants seem to like the course structures and open topics. One reason for good feedback can also be the possibility to create something “concrete”, a model of a device, unlike in theory-oriented courses.

In the future, CAD/CAE-related courses will be divided more clearly between bachelor’s and master’s degree programmes. In the bachelor’s degree programme, basic tools and methods to create geometry will be taught. In the master’s programme, teaching will be focused on how to support design process with computer aided design and simulation software applications.

Year 2016 new master’s degree programme will start at Aalto University. According to current plan, separate CAD/CAE courses are not planned. However, topics from courses CAD Basic Course, CAD Advance Course and CAE Project will be included in 1st year of master’s degree programme. Current plan is to create a half year and a 15 cr Mechanical Engineering course, where basic iterative product design process will be taught. During the design process, different kind of computer aided tools will be presented and applied to enhance the work of the project teams, both in machine design and mechatronics courses [10].

REFERENCES