COMSOL CONFERENCE
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FH AACHEN
UNIVERSITY OF APPLIED SCIENCES

Teaching Simulation Methods with COMSOL Multiphysics

Master Courses at the FH Aachen

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Presentation Outline

Introduction

> Simulation of components and processes becomes more and more important in industry[1,2].

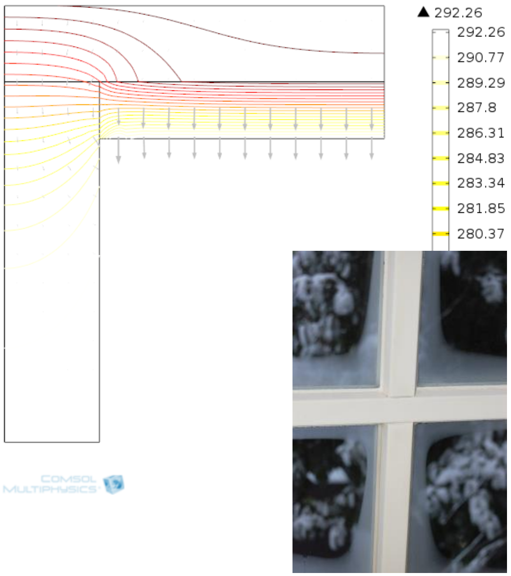
> Necessary to train young engineers how to apply simulation software [1,3,4].

> In addition it is important to learn „soft skills".

> Therefore <u>two consecutive elective courses </u>were established at FH Aachen:

- Simulation Methods
- Simulation and Optimization in Virtual Engineering

> <u>Focus on COMSOL Multiphysics</u>, because it is widely utilized in industry and very intuitively to handle.



General Setup of the Courses

„Simulation Methods“ and „Simulation and Optimization in Virtual Engineering“

- > FH Aachen, Faculty of Energy Technology.
- > Int. Masterprogram „Energy Systems“, 4 semester, 180 Cr., language English.
- > 150 Students (65% International, 35% Germany).
- > For Bachelors from mechanical and electrical engineering.

Source: FH Aachen

Table 1: Topics for both courses

	Mathematical / Simulation Topics			Physical Topics		
	Basics on PDEs	**Geometry Handling**	**Numerical Solvers**	**Conduction**	**Radiation**	**Convection**
Simulation Methods	- Vector Analysis - Mathematical Formulation	- Import of CAD Structures - Geometry Builder in COMSOL	- Finite Difference Method - Numerical Linear Algebra - Newton's Method	- Mathematical Description - Boundary Conditions - Homogenization	-Stefan-Boltzmann Law	- Forced Convection - Free Convection - Fluid Dynamics
	Optimization Theory	**Multicriteria Optimization**	**Numercal Solution Methods**	**Heat Transfer**	**Structural Mechanics**	**Multiphysics**
Simulation and Optimization in Virtual Engineering	- Unconstrained Problems - Constrained Problems (KKT) - Convex Problems	- Optimizing two objective Functions - Weighted sum approach	- Decent, Steepest Decent Method -Penalty and Barrier Function Methods - Numerical Derivatives - Opt. with MATLAB	- Conduction - Convection - Radiation	- Mechanics of Materials - Eigenfrequencies	- Heat conduction and mechanical deform.

- > Elective
- > 5 Cr.
- > 15 weeks
- > Up to 20 students

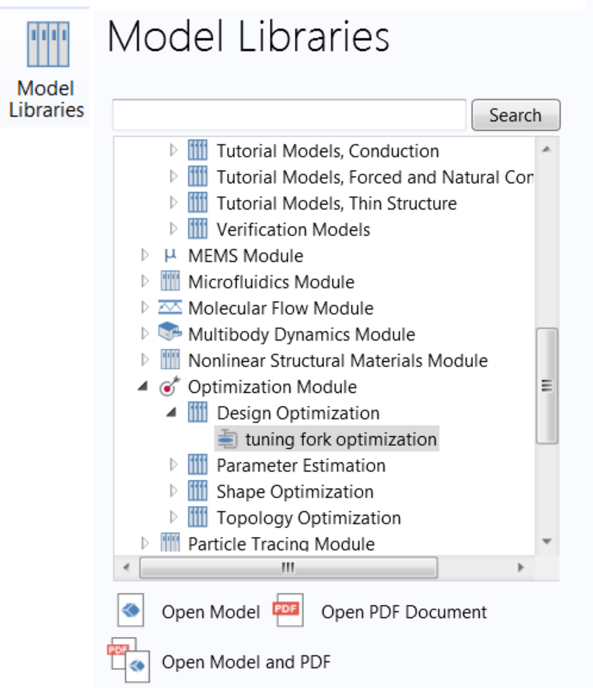
Applied Teaching Methods
Revised Bloom's Taxonomy

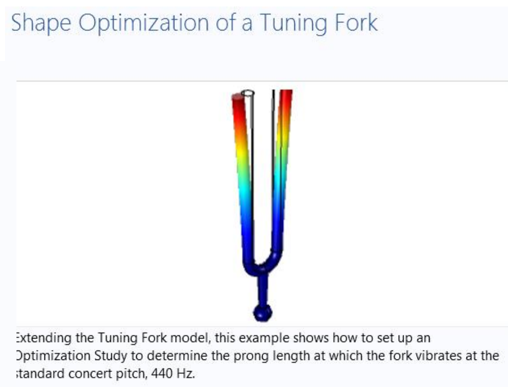
Table 2: Example for „Simulation Methods" [5]

Structure of the Cognitive Process	1st Level (1.-3. week)	2nd Level (6. & 7. week)	3rd Level (11. & 12. week)	Project (13.-15. week)
Remember	Repetition PDEs; Differential op.;			Math., phys. and Comsol basics;
Understand	Differential op.; Heat equation; Boundary cond.;	Direct and iterative solvers;	Math. principle of natural conv.;	Practical problem;
Apply	Interpr. of math. formulation.; Application in Comsol.;	Example in Matlab; Transfer theory to Comsol;	Simulation series in Comsol;	Implementation in Comsol;
Analyze		Convergence criteria;	Criteria for convection and conduction;	Project schedule; Analyze results;
Evaluate			Diff. types of flow regimes;	Reviewing and judging the results;
Create				Putting results together; Creating report and presentation;

Applied Teaching Methods
Potential of COMSOL Multiphysics in teaching

- > The theoretical parts of the lectures could easily combined with practical parts (understand - apply).
- > As nice assistant, COMSOL provides the Model Libraries.





Source: COMSOL Multiphysics 4.4

- > First the whole description was delivered.
- > Later on, more and more steps were left out.

Applied Teaching Methods
Potential of COMSOL Multiphysics in teaching

> Example:

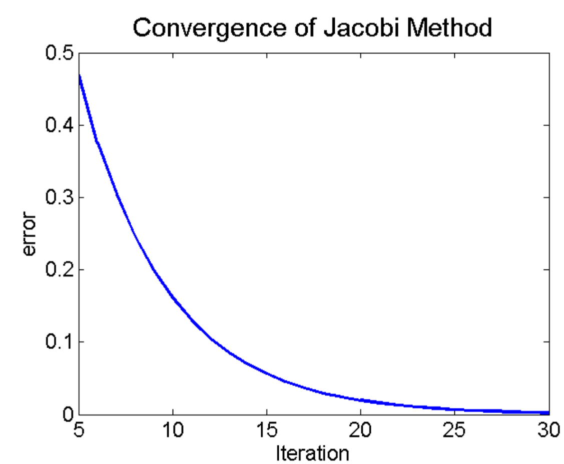
- The students investigate the itereative Jacobi and Gauss-Seidel and the SOR method

- Two simple linear systems of equations were considered in Matlab and solved by the Jacobi method.

$$\begin{pmatrix} 2 & -1 & 0 & 0 \\ -1 & 2 & -1 & 0 \\ 0 & -1 & 2 & -1 \\ 0 & 0 & -1 & 2 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \\ 1 \\ 0 \end{pmatrix}$$

- One method converged. This leaded to mathematical analyses of convergence criteria (analyze)

$$x^{(k+1)} = D^{-1}b - D^{-1}(L+U)x^{(k)}\,, \quad k \in \mathbb{N}$$



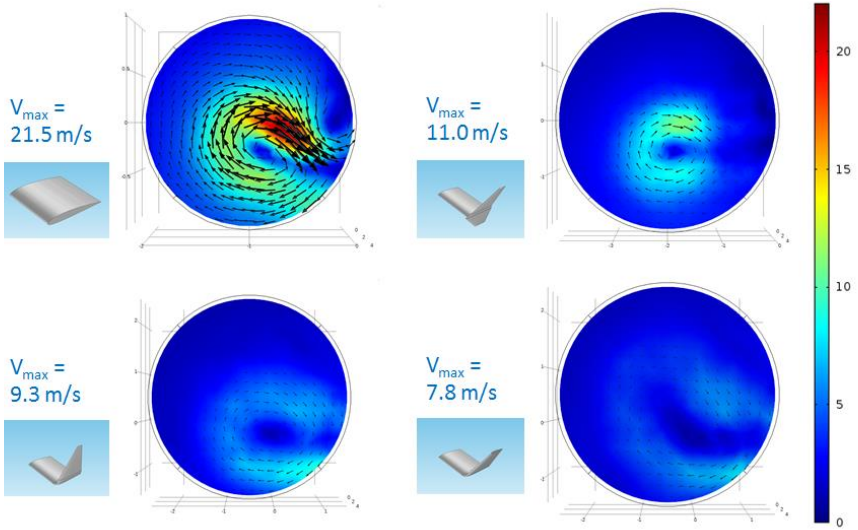
- New knowledge was directly related to the available COMSOL solvers and possible manipulations.

Example for „Simulation Methods“

Comperision of different wingtip types

- Students‘ choice and not a predefined topic
- Investigating the principle of wingtips (winglets) to have smaller vertices and less drag in the case of small velocities.

  As a result the fuel consuption is reduced.
- First, they have to create the geometries: Work around with a MATLAB program, which parameterizes the wing profile (NACA 2415). So they were able to create the geometries with the goemetry tools from COMSOL.



- They investigate
  - startionary solution
  - transient cases
- They showed how vertices develop and that wingtips reduce them.

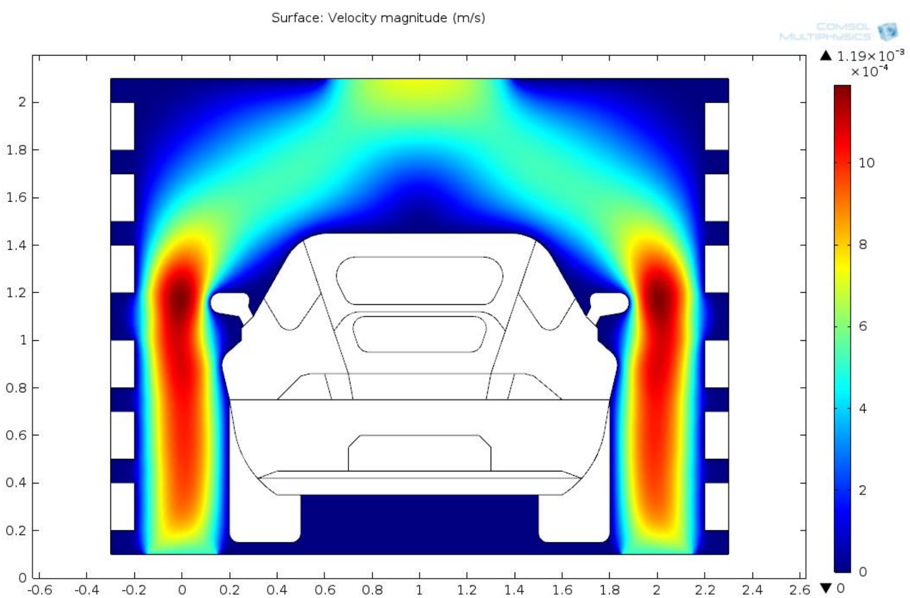
Example for „SimOpt"

Optimiziation of a Paint Drying Process

> Project given to the students as first project before they work out the final project on their own.

> On the oven wall are several infrared lamps installed to heat up the car body. In addition there is air flowing from two inlets on the ground to the outlet on the top.

> The studends should set up the optimization problem with the following two goals:



- Controlling the lamp power in order to achieve a uniform temperature at the car body
- Save energy

> To achieve this, they use the LiveLink to MATLAB

Conclusion and Outlook

Conclusion

> Combination of theory and praxis was successful.

> Motivation of the students was very high, espacially in the projects.

> By exchanging examples from COMSOLs‘ model library with industrial cases, teaching will be closely related to ongoing research.

Outlook

> In future, improvements by E-Learning are planned, where the software handling is shown in short videos.

> It is planned, to give the course as block course.

References

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4. P.J. Butler and M.C. Ferko, FEMLAB Modules for Bioengineering education, *Proceedings of the COMSOL User's Conference Bosten 2005*, (2005)

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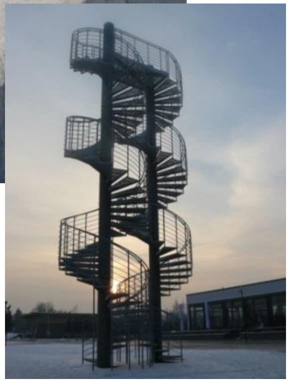
Thank you for your attention!



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