Industry-Oriented Fluid Mechanics Laboratories for STEM Education: A Comparative Study

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Most engineering study courses (i.e. mechanical engineering, civil engineering etc.) at TU Berlin do not differ from each other in the first semesters, because they do have the same lectures to impart basic knowledge. By experience, it is hard for students to abstract what this knowledge can be used for in the later study stages or in their later jobs. Consequently, young students are not able to understand their upcoming responsibility and how society will benefit from them.

The idea of WiSPr Laboratory is to create the link between study matters and society's needs. Furthermore, a connection between different engineering disciplines is created right at the beginning of their studies. A good way to fulfil employer's requirements is to design a course collaboratively and prepare students for their later jobs. Therefore, an everyday object (i.e. coffee machines, dryers, washing machines, etc.) is taken and looked at in detail. The multi-facetted engineering nature of these products is underlined and interdisciplinarity is emphasized.

2.2 Design and Execution

At the example of a washing machine paddle (**Fig. 3**), students experience development processes in the industry. Therefore, they visit research and production facilities and get to know the industrial routines. Moreover, the students apply innovative, numerical methods for flow simulation (see also **Chapter 5**). In a laboratory session, results of the simulation are compared with reality by using a test bench.

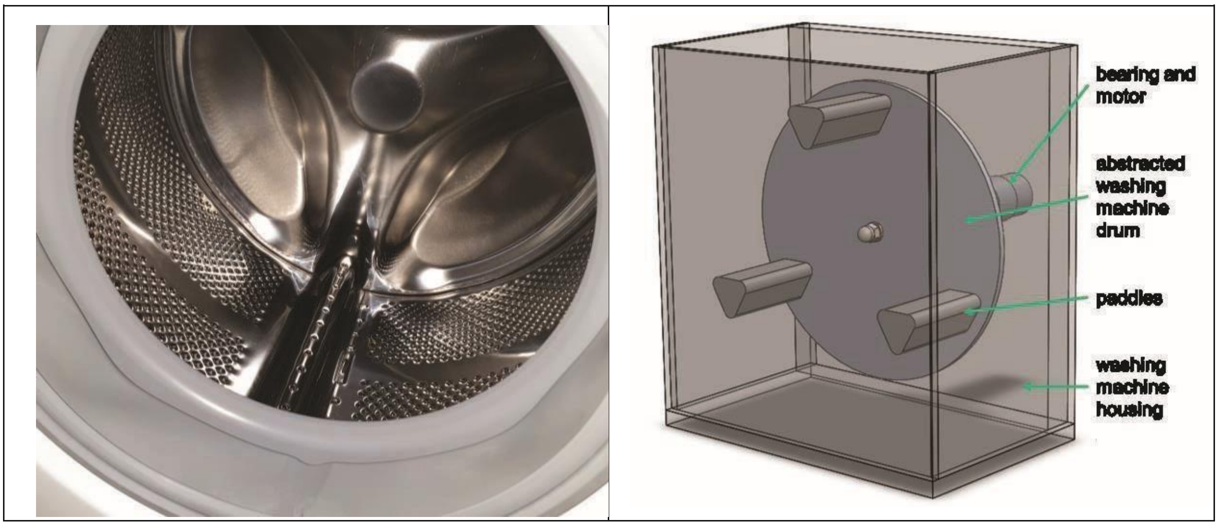

Fig. 3: Washing machine paddle inside a washing machine drum (l.) and washing machine test bench for investigation purposes (r.)

Even if it does not show, a washing machine paddle (**Fig. 3**) is one of the most complex elements inside a washing machine. Given task for the students is to simplify the washing machine drum and design their own paddles with certain chosen abilities. The whole design process is supported by different industrial project partners and research assistants. WiSPr Lab splits into five steps as illustrated in **Fig. 4**.

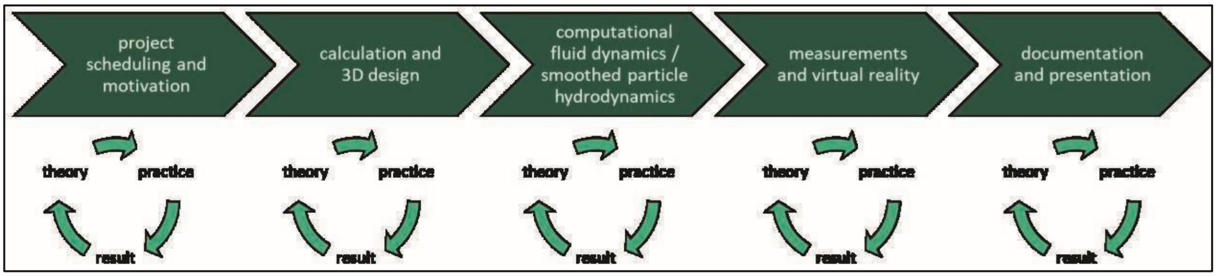

Fig. 4: Design process in WiSPr Lab according to problem-based learning philosophy

The first step contains motivational excursions into research and development facilities of different industrial project partners. Students gain insight on washing machine design, product life cycles, washing processes and textile testing. Time and project management skills are taught.

After understanding the purpose of washing machine paddles, students are encouraged to design their own washing machine paddles in groups of four by choosing a number of requirements their paddle has to accomplish. Students design their paddle in a way they think it would fulfil set requirements by using a 3D-CAD[1] software called "SolidWorks" (step 2). Afterwards, in step 3 these paddles are used for numeric fluid simulations using a smoothed particle hydrodynamics software called "DICE[2]". The results of the simulation are used to investigate if the paddles accomplish previously defined requirements. If not, the design of the paddle is changed and iteration processes are started. **Fig. 5** shows all paddles designed in winter term 2018 after their last iteration.

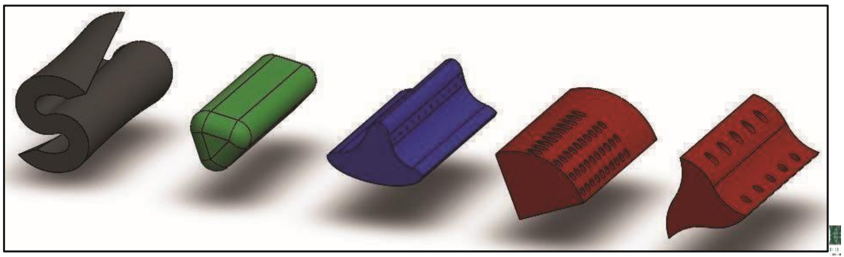

Fig. 5: Paddles designed by students using a 3D-CAD software in winter term 2018 (each paddle was created to fulfil previously set requirements)

Step 4 is used to impart knowledge about product design using virtual reality and to prepare for upcoming measurements at a test bench. Therefore, an excursion to a Virtual Reality room called "CAVE" is arranged. By wearing shutter-glasses the designed paddles are projected into the room, therefore appearing 3-dimensional in front of the students. A tracking system and the rising immersive effect allow students

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[1] CAD: Computer Aided Design

[2] For further information please visit www.dive-solutions.de

to interact with their geometry. Furthermore, students' paddles are put into a virtual test bench to explain upcoming (real) measurements. Step 4 is completed by executing measurements on the real test bench and comparing results with previously done simulations.

Fig. 6 compares the simulation result with test bench investigations for the blue paddle rotating counterclockwise. Looking at the vortex formed in the middle bottom, simulation and measurement show an accurate conformability.

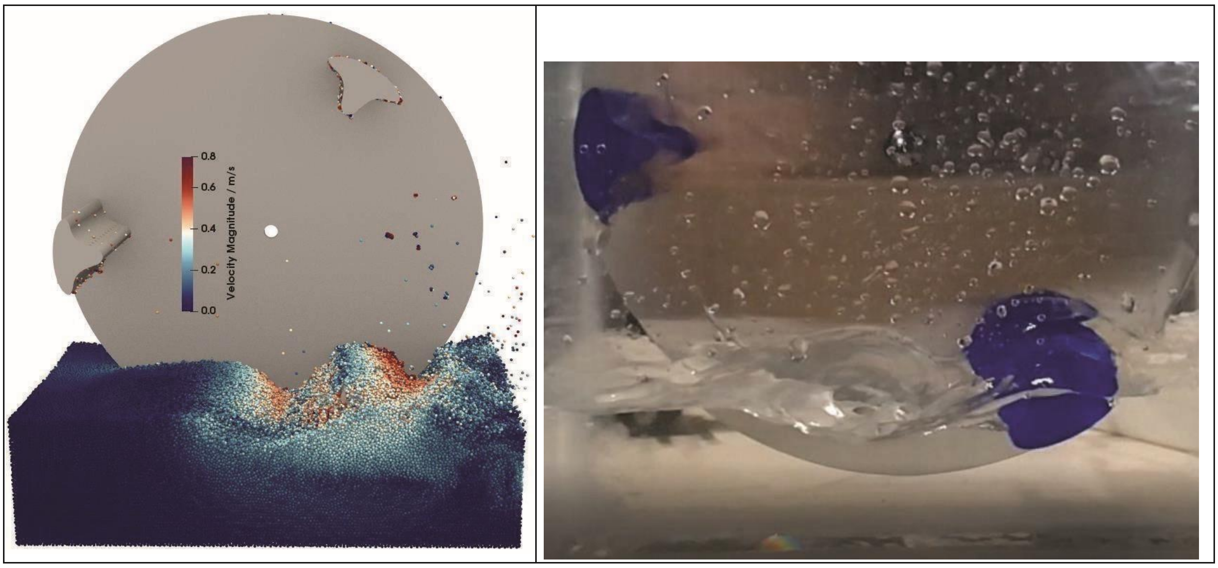

Fig. 6: Results of numerical simulations using smoothed particle hydrodynamics (l.) showing a washing machine paddle diving into water compared to test bench investigations (r.)

Last but not least, step 5 covers scientific writing and presentation skills. Students create templates using MS Word and MS PowerPoint, which can be used for their later study courses. The results of each group are presented in front of all MINT^{gruen} lecturers and students.

During the steps mentioned above and illustrated in **Fig. 4** several engineering skills are achieved by the students. The most important points are summarised in **Fig. 7** including duration and contents of each step.

Step	**Duration**	**Contents**	**Achieved skills**
1	*4 weeks*	Motivation and topic introduction, Interdisciplinarity in engineering, Project management	Organisation of group projects, Time management, Creating project schedules with MS Excel, Excursion into Research and Development center, Excursion into Textile Material Testing Laboratory, Connection between mechanical engineering and textile & clothing technology
2	*3 weeks*	Basics in Computational Fluid Dynamics (CFD) and Smoothed Particle Hydrodynamics (SPH)	Basic knowledge in Fluid Dynamics, Proper usage of SPH-software (dive solutions' dice), Basics of post-processing software (Paraview)

3	*2 weeks* Computer aided design (CAD)	Introduction into 3D modeling, Basic usage of CAD software, Advanced usage of CAD tools (scripts & macros), Manufacturing of student's washing machine paddle
4	*3 weeks* Measurement techniques, test stands and Product design by using virtual reality,	Purpose of test, virtual reality Usage of sensors, Measurement of each group's paddle, Advanced usage of MS Excel (graphs, functions)
5		*3 weeks* Writing and presentation skills Creating templates for MS Word, Basic usage of MS PowerPoint, Scientific writing recommendations

Fig. 7: Contents and achieved skills in WiSPr Laboratory

3 RESULTS AND TEACHING APPROACH

Analysis reveal that more than half of the students participating in the orientation program in 2018 choose a MINT topic for their later studies (**Fig. 8**).

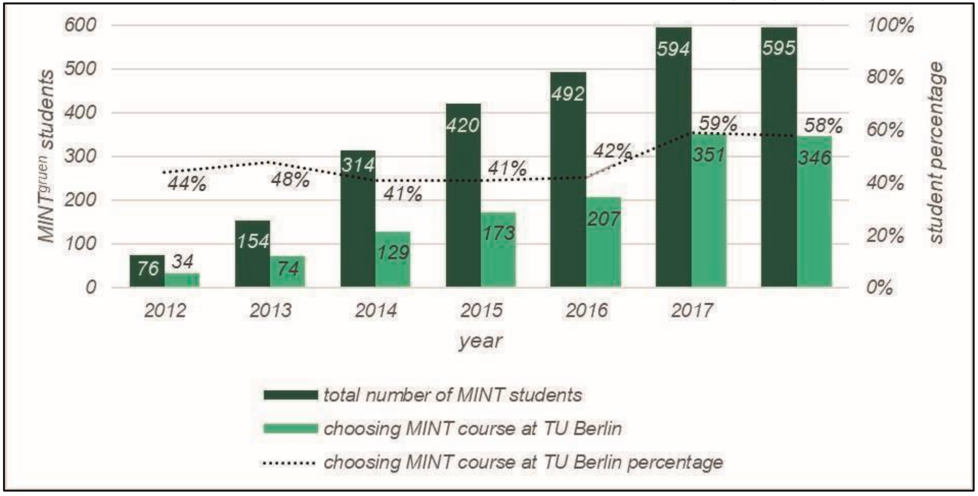

Fig. 8: Number of students considering a MINT related study course at TU Berlin

Even students who leave the university and start an apprenticeship consider the contents of WiSPr as useful for their later jobs. The WiSPr Laboratory as a whole was rated in the winter term 2018 with “very good” (**Fig. 9**). Despite the simulation part (advanced numerical fluid mechanics) students consider WiSPr Laboratory equally difficult compared to other courses attended (**Fig. 10**).

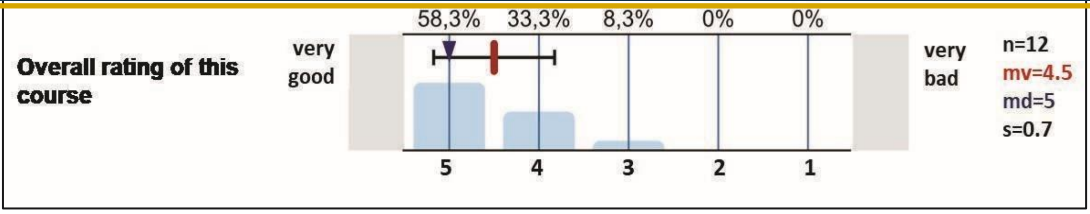

Fig. 9: Students' overall rating of WiSPr Laboratory in the winter term 2018

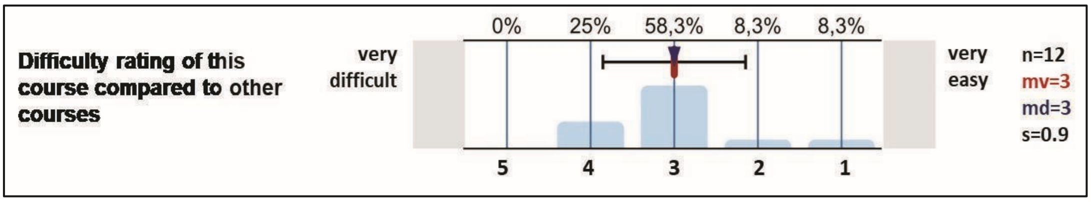

Fig. 10: Students' difficulty rating of WiSPr Laboratory compared to other courses in the winter term 2018

4 SUMMARY AND ACKNOWLEDGEMENTS

Whereas lectures mostly use frontal teaching methods the Project Laboratories focus on practical tasks and give students the possibility to create a STEM-related object on their own. The teaching concept of this Industry-oriented Project Laboratory contributes highly to the orientation of our students. A huge field of fluid mechanical engineering is covered. Students gain a diversified insight on fluid mechanic related topics and their field of appliance. Due to the practical concept of the laboratory students achieve various engineering skills and working methods which can be used in many study courses, apprenticeships, or even in their later jobs. Due to the teaching of basic and advanced skills regarding engineering software (Python programming language, MS Excel, MS Word, MS PowerPoint, SolidWorks), students are well prepared for their course of study. In this program students get supported in general studying related aspects as well as fluid mechanic related topics.

5 APPENDIX – SMOOTHED PARTICLE HYDRODYNAMICS (SPH)

Smoothed particle hydrodynamics (SPH) belongs to the meshfree methods in computational fluid dynamics (CFD). Whilst traditional CFD uses grids to solve numerical fluid dynamics, the simulation method Smoothed Particle Hydrodynamics approximates fluids as an accumulation of particles moving freely in space. Every particle can be seen as a moving interpolation point. The physical field can thus be evaluated at those points by interpolating the properties of surrounding particles (see **Fig. 11**). This eliminates the need for grid generation and easily solves some of the most challenging cases of fluid mechanics. SPH efficiently solves multiphase and free surface flows, as well as moving machinery (such as gear boxes lubrication or mixing tanks). Many use cases are shown below (see **Fig. 12**).

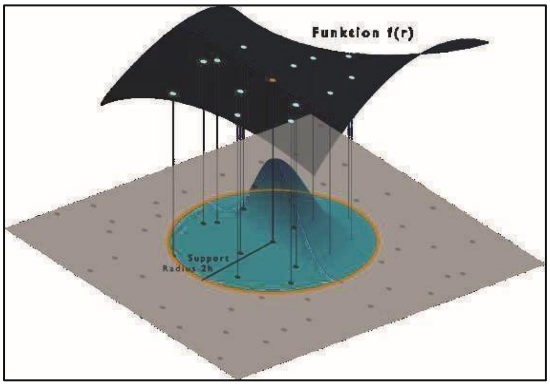

Fig. 11: Decreasing influence of a particle (center) on its direct neighbours

Fig. 12: Extraction of use cases for Smoothed Particle Hydrodynamics
Gear box lubrication (top l.), fluidic oscillator (top r.),
sewer system (bottom. l.), sedimentation transport (bottom r.)

Feel very welcome to visit www.dive-solutions.de for more information.

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