Physicist of the future: Multiphysics simulation models in engineering assignments

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INTRODUCTION

With the current technological and societal challenges there is a growing need for the application of physics in engineering systems. The demand of skillful physicists who are able to provide engineering solutions to technological and multidisciplinary problems is steadily increasing. The inclusion of the professional practice and industry problems in educational projects as a vehicle to foster the ability to design and innovate in changing environments and conditions [1-2-3] is not new. However, designing

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engineering solutions embraces an iterative decision-making process to search for multiple alternatives and solutions. This is a valuable addition for our courses in physics [4]. The nature involved in the dynamics of solving engineering design problems comprises a combination of advanced physics concepts, and engineering expertise. In this paper we present the approach of the *Physics of Engineering Problems* (PEP) graduate course aiming at developing students' problem-solving abilities at the Eindhoven University of Technology (TU/e), the Netherlands. In this study we explore how students conduct simulations with the digital platform Comsol Multiphysics. We present the effects of the online tools on students learning to simulate engineering thinking as a result of this first experience. We also illustrate a number of problems we encountered regarding lacunas and capabilities, such as analysis of equations, graphical representation and quantitative analysis; synthesizing and drawing original conclusions. In addition, we also provide an overview of difficulties with the simulation tool capabilities and the time schedule of the course, together with the feedback from companies and students on the course.

1 RESEARCH IN TEACHING PHYSICS

1.1 The relevance of changing curricula

The paradigm shift in teaching physics from a traditional and theoretical orientation towards the application of physics into a problem oriented engineering design approach is the essence for the engineering physics of the future. In professional life design engineers make use of tools for simulations. Within this rationale, the approach is to teach how to apply simulation models in realistic schemes and industry problems. Empirical literature on computer simulations to teach physics shows evidence on students' gains. Computer technology education engages students in an interactive environment in which designs of students resemble dynamic and physical principles of daily life in different engineering fields [5]. Learning physics concepts through simulations occurs by illustrating physically highly visual and dynamic representations with accuracy that engage in a simulated environment [6]. The key educational features of computer simulations are based on a constructivist approach as students create own knowledge by learning from explorations of applying how physics principles work when building virtual objects in simulations and testing how they work [7], and getting dynamic feedback from that system [8]. Furthermore, researchers argue that simulations empower students' motivation, gives responsibility in building factual and realistic models, visualizing problems and solutions, developing cognitive skills and attitudes [9]. In addition, research on computer simulations indicates that engaging students in authentic scenario's and exploring scientific phenomena and animated models stimulate students' analytical and critical thinking [10-11]. Other approaches such as mathematics modelling [12] address a systematic method to think in steps by firstly analyzing the questions and making estimations from a mathematical perspective. Learning from making propositions and test them motivates the active participation of the students.

But research experiences on using technology to enhance students' conceptual understanding of physics is not first-hand information and empirical literature abounds in this respect. Since the last decades in the 20th Century numerous studies have been conducted in order to investigate misconceptions and students' problems in learning problem solving, analogies, models, and understanding regarding relationships between representations and derivations [13]. Studies on classroom practices indicate that integrating technology and combining this with feedback into instruction, providing just-in-time advice on practical assignments in problem solving improves cognitive development [14], and foster students' problem solving strategies [15-16-17]. Furthermore, the combination of feedback, practice and instruction together with active learning methods has yielded interesting results in students' understanding by adapting the instructional design of physics classroom into models such as *studio classroom* in teaching for instance quantum physics [18], engaging students' in questioning [19] or through educational methods such as Workshop Physics [20], Socratic dialog lab [21], Active learning sets [22], tutorial-based instruction [23] and Peer Instruction [24-25]. These models integrate multiple-choice conceptual questions and have students to answer through audience response systems (ARS) clicker-type devices on understanding conceptual material. In addition, the power of *just-in-time* feedback tool by displaying answers and providing an overview of individual understanding has demonstrated positive empirical evidences in understanding [26].

Finally, problem-based and project-based learning methods applied to engineering fields foster collaboration resembling the interdisciplinary authentic industry scenarios. Planning experiments and simulations, modelling processes and making measurements, refining the data into analysis of models has proved how modern and efficient computational tools into project team assignments can bring about new prospects in engineering education [27].

2 TECHNOLOGY, CONTENT AND DIDACTICS

In this study we analyze how the different methods support students to acquire engineering skills i.e. use and apply a systematic problem-solving approach to define, implement and validate multiphysics models. Following the studies on students' misconceptions in physics and grounded in literature on how novice students make use of trial-and-error methods which is not systematic to solve engineering problems rather than working on a solution-oriented approach [12], we focus on an educational approach towards teaching engineering physics in which knowledge is applied using computer simulation models.

The rationale for a paradigm shift in education is two-fold: first of all, it becomes essential to integrate educational methods such as simulations to firstly foster students digging into fundamental concepts and how they work in solving engineering problems rather than applying equations and work-out examples [28]. Secondly, the integration of blended-learning [29] and computer-based education has yielded interesting students' gains in understanding concepts and in solving engineering problems [30-31]. Thirdly, the use of visualizations allows students to understand better the underlying physics principles and the effects of the application of these principles. Grounded in educational theories, we considered the Technological Pedagogical Content Knowledge (TPACK) model [32] as the framework to teach difficult physics concepts by combining this with computer simulations.

2.1 The Physics of Engineering Problems (PEP) course

The *Physics of Engineering Problems (PEP)* course is part of the graduate Applied Physics (AP) university master program. Within the AP master study program two certificates have been introduced, one for physics research and one for physics engineering. The physics engineering certificate caters to the need for physicists with more inclination towards solving technological problems. The graduate course of *Physics of Engineering Problems* (PEP) is part of this certificate. Within this course we are trying to innovate educational methods which have a real meaning for the students' preparation as graduates while dealing with educational challenges such as misconceptions in problem solving. In addition, we also want to create a breakthrough in teaching physicists to use models for engineering problems in our department and to influence teaching and learning. In this regard, this course deals with modelling of engineering problems using a systematic approach of the relevant phenomena, which are to be implemented in a multiphysics simulation model. In the case of the PEP course, the mathematics modelling systematic way of thinking [12] allows students to use phenomena in steps by analyzing the questions and making estimations from a mathematical perspective.

As a learning process, analyzing, synthesizing, testing of hypothesis, and observing the outcome, are taught as a repetitive cycle to approach and uncover an industrial engineering problem or to apply it in a systematic engineering solution.

But mastering the tool is not the only instructional method to teach students to develop critical thinking in solving engineering problems in the PEP course. The critical thinking approach to solve engineering problems consists of four steps in a cyclic learning process, i.e. observe, analyze, conclude (formulate a hypothesis) and test (see *Fig. 1*).

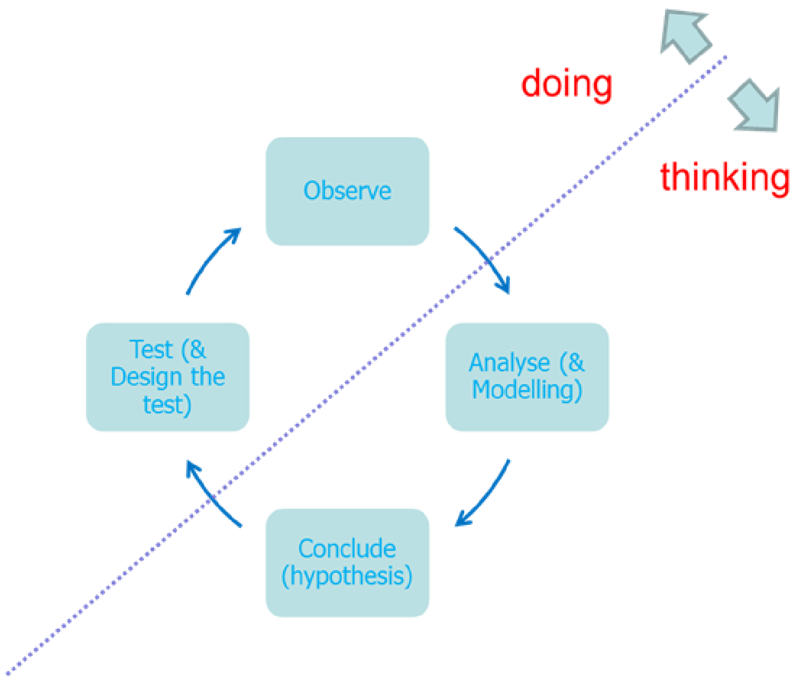


Fig. 1. Four steps in the learning process

The sequence is that the students select the essential physics to be modelled in discussion with the problem owner and the teachers who act as consultants. Next step is to give the relevant equations which describe this physics. Then the students have to give a back-of-the-envelope estimation, which results in the quantitative expectations for the outcome of the simulation model. In the end of the report the students have to discuss in how far the simulation model agrees to their expectations, as a healthy check on the credibility of the model.

2.2 Physics of Engineering Problems assignments

Within the PEP course students are to work on two assignments. The initial assignment is the same for all the students, for which they have to provide an individual simulation report. Their task is to find a recipe for “The Perfectly Boiled Egg”. The problem is to provide a soft boiled egg, with the yolk cooked (>65C) but remaining liquid (<70C) while the egg white (albumen) is already solidified (80C to 100C). Basic considerations are the diffusion of heat, material parameters, size or weight of the egg and the cooling of the egg. Complications can be considered such as the air chamber blocking the diffusion of heat if the egg is not fresh, a convective flow, the shell, transition heat during phase change, and temperature dependent material parameters. About two weeks are available with a study load of 14 hours per week. The students present their recipe and perform on a stove for an expert jury of two chefs de cuisine.

Fig. 2. Students demonstrate the simulated recipe for a jury of two chefs de cuisine

The second and main assignment is selected by the teams of students from a number of problem statements from industry. The themes of the industry problems are:

- Vibrations in a system of tubes with a flowing liquid caused by turbulence have an impact on a machine and should be diminished
- A company would like to have a guess for the distortion of images from a mirror due to the heating of the mirror by the light beam
- A mass spring system has to support a heavy impact while the maximum pressure in the hydraulic damped system should remain below 100bar
- The efficiency of a water turbine is to be optimized by the number of lamellas and the rotation angle in the water flow
- An underwater modem shows too little signal above the water surface and the question is if this can be optimized by orientation or transmitted frequency

In order to teach students a problem-oriented way of thinking, the students go through discussions with the problem owners from the industry who provide formative feedback for the improvement of the model. Within this cyclic process, students are to model and simulate in the analysis phase. It often happens that engineers jump from observation to conclusions without consciously analyzing the data and the relevant physics. Conclusions should be supported by the analysis, Students have to learn that conclusions should often be regarded as a hypothesis which is to be tested by further assessment. Within this approach the modelling activity is part of the analysis. The student has to reason rationally, argue about conclusions by analysis.

The result of the modelling activity can be an interpretation of the fitted data for which the analysis provides the reasoning. Likewise, if no data is available, the result can be a recommendation for the problem owner to carry out experiments to collect data on parameters which are found to be essential in the model. It takes an effort to prevent that students just hit the buttons of the keyboard for simulating without reasoning. In the end, the reports are assessed by use of rubrics (see section 4 in this paper). Note that in contrast to the model for analytical purpose, the aim of constructing a model could also be to provide a descriptive model, such as for data analysis, or for transfer of knowledge. This type of descriptive models is excluded from this course as the focus is on the analysis in terms of physics.

2.3 A blended approach for engineering physicist

Active learning and blended-learning methods, such as a project-based learning, combined with computer technology and simulations are used in this course to stimulate students' abilities in applying theoretical knowledge in engineering problems. In addition, we also support students' differences in prior knowledge and lacunas by developing weblectures, i.e. short focus-oriented themes, by which both the teachers and invited guest lecturers zoom into specific areas of physics and ways to perform estimations. The physics concerns for instance heat conductivity or the Maxwell equations. The methods for estimations include the famous approach of Enrico Fermi decomposing the problem into elementary parts, the so-called Fermi problem, the use of basic equations for a back-of-the-envelope estimation, or a 1st order approximation.

It is regarded as a key ability of physics engineers to perform estimations, for which this course offers an opportunity. The added value of integrating blended-learning methods is that the face-to-face contact time is reinforced by additional content material devoted to optimize the students' self-study time on one hand. On the other hand, we aim to tailor-made education for those type of students with differences in learning styles and prior knowledge

3 COMSOL MULTIPHYSICS: COMPUTER-BASED TECHNOLOGY

This study aims at exploring how students learn with a software system such as Comsol Multiphysics to conduct simulations. Comsol Multiphysics is based on advanced numerical methods, for modeling and simulating physics-based problems. It offers a simulation environment based on the original Matlab solver engine to solve sets of coupled partial differential equations for cross-disciplinary model simulations with a unified workflow for electrical, mechanical, fluid, and chemical applications with a recent addition in the field of optics. COMSOL Multiphysics includes a set of core physics interfaces for common physics application areas such as structural analysis, laminar flow, pressure acoustics, and transport of diluted species, electrostatics, electric currents, heat transfer, and Joule heating. This platform is chosen for its highly accessible graphical interface. As an online classkit, COMSOL Multiphysics allows large numbers of 30 students or more to logon. This allows teams of students to develop experiments and carry out simulations. The student learns to use a multiphysics simulation software package with very little effort. The idea is to identify the relevant physics which play a role in a stated multiphysics problem. Furthermore, this virtual environment allows to include own partial differential equations which describe for instance material properties, parameters, etc. and create new physics interfaces and models from these equations. For the relatively limited complexity an Intel i7 processor with 8GB RAM is sufficient. This pushes students to limit the use of memory by making choices. Examples are to limit the number of meshpoints and Degrees of Freedom by assuming symmetry, simplifying the mesh, leaving extraordinary thin or thick layers out, decoupling types of physics by simulating in a sequence instead of simultaneously, and considering simplifications of the model such as 2D instead of 3D. Thus the standard laptops of the TU Eindhoven offer enough capabilities to run the required simulations in this course.

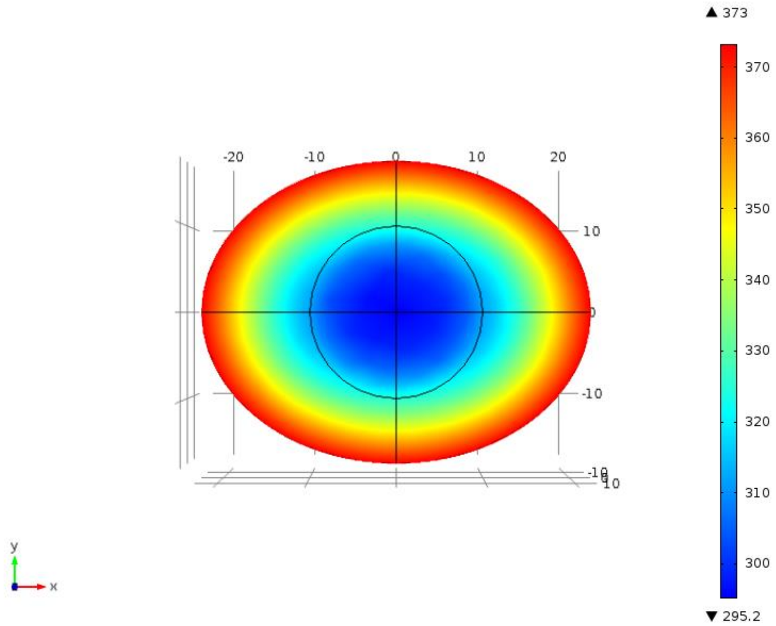


Fig. 3. Egg model by student in boiling water after 360 seconds

4 METHOD

4.1 Assessment criteria

To analyse students' simulations and project reports and results we developed assessment criteria aligned to the learning outcomes of the course. The assessment criteria consist of the following components:

- systematic approach to the engineering problem
- application of the learning cycle
- communication, and
- content.

The rubrics, i.e. assessment matrix, have been designed with the purpose of appraising the progress of the students, on the one hand. On the other, rubrics have been applied to provide feedback as well, i.e. *assessment for learning*, during the course. In addition, the assessment criteria are used for internal validity purposes and also to create inter-rater reliability between assessors as both company experts and university teachers were to assess the reports of the students. We provide in *Table 1.* an example of some of the assessment criteria used in the form of rubrics.

Table 1. Selection of assessment criteria and rubrics

				Scores 1	Scores 6	Scores 10
	learning aspect	Demonstrated Capability	Dimension	Not complying	Progressive	Mature
1	Systematic approach to the engineering problem	Showing understanding of the need or benefit for the problem owner	Give a description of the problem and the motivation behind it	No problem statement	The problem is stated in the introduction of the report	The problem is stated in the introduction of the report including the context behind the need
2		Choose the selection of the relevant physics which is to be modelled	Give a problem description in terms of the physical behaviour in the system *1*	No description is given of the phenomena which are to be modelled	A description is given of the phenomena which are to be modelled	A description is given of the phenomena which are to be modelled with a reasoning for the expected relevance
3		Formulation of the problem in mathematical terms	A mathematical formula is given to describe the engineering problem *1*	No explanation of the differential equation is given or is largely incorrect	For some terms of the differential equation the meaning is given	For every term in the differential equation the meaning of the selected terms is given supported by reasoning
4		Back-of-the-envelope calculation as a rough estimate	Give a rough estimate for the outcome of the model simulation *1*	No estimation is given	An estimation is given for some parameters in the model system	Back-of-the-envelope estimation is given for the critical parameters in the model system
5		Verification and Validation	Verification of the quality of the mesh	Choice of mesh is not supported by reasoning in the report	Discusses the choice for the mesh density in the report	Includes simulation results for three different mesh densities and judges the effect on simulation results
6			Validation by external knowledge *1*	Simulation is presented without validation	Comparison with either estimation, or data or known behaviour	Comparison with expectations from estimation, and data or known behaviour
7	Apply the learning cycle	works in steps and separates observation from analysis, draws conclusions using analysis, tests hypothesis, observes the resulting data from the test, and if necessary reformulates the model	separates observed data from analysis and conclusions	Mixing observation of data with conclusions in the same section	discussing of the observed behaviour, separated from conclusions	states given data with a discussion of observations, separately from analysis or conclusions
8			draws conclusions from analysis *1*	intuitively draws conclusions	uses the model analysis to come to straightforward conclusions	comes with careful conclusions from modelling analysis
9			be open to test a hypothesis, a critical attitude *1*	applies a fit procedure to test if data correspond with the model formula	hypothesis is validated by observing the outcome of the test and used to improve the model	hypothesis is validated by observing the outcome of the test and used to improve the model while showing understanding of the underlying problem
10	Communication	Reporting	graphical representation, choice of axis/parameters *1*	message of most graphs is not stated	message of the graphs can be stated more clearly by choice of axis or figure caption	graphs and figure captions are insightful and speak for itself
11	Content	Model execution	Quality of model analysis and execution, credibility of the solution *1*	The model is hardly believable	The model shows features which match expectations	The model shows relevant features which match expectations and lead to new conclusions
12			Problem oriented approach	The report does not answer to the problem statement	The report gives a conclusion based on the modelling results	The report gives a conclusion based on the modelling results, creating insight for the problem owner

4.2 Authentic assessment and input from the industry

The experts from the industry have played an important role in the monitoring of the process both in giving formative feedback and in the assessment of students. The feedback sessions consisted of individual meetings of the company problem owner with the team of students who selected the company case. In the meeting the concept-of-proof simulation model was presented and discussed. The choice for individual team presentations instead of presentations in plenary sessions is meant to stimulate interaction between the students and the professional with focus on the case. And the input by the industry did include feedback on the concept just-*in-time.* In addition, by addressing small-scale feedback on practice and simulations and direct instructions by the teachers we aimed at addressing students' individual needs and learning problems and lacunas.

Both industry representatives and university teaching staff have applied a reference criteria framework in the form of rubrics to assess the work of the student teams.

Table 2. Example score of a problem owner from a company for one students' team

	C or D. problematic	B-. beginner, not strong	B. normal	A. good, mature	A+. excellent	Score
Dimensions						
Performance, general	Poorly	should have done better	**Meets requirements, with some help**	Meets requirements	Exceeds requirements	B
Systematic approach	None	needed guidance for most steps	works structured with normal help	**works structured independently**	works structured by nature	A
Inventivity in problem solving	No surprise	Surprise for laymen	**Surprise for peers**	Surprise for professionals	Surprise for supervisors	B
Inititiave, Formulating the problem description	No problem formulation	Only with help of supervisor	Takes initiative, but relies heavily on supervisor	**Needs little help for further elaboration**	Needs no help for furher elaboration	A
Seeking expert advice	Does not realize when external expertise is needed	**Waits for expertise to be offered (no active seeking for expertise)**	Actively searches in project environment for other expertise	Actively searches in project environment and elsewhere for other expertise	Actively searches for expertise inside and outside, and involves others into the project	B-
Communication skills (written only)	explanations are not understood mostly	explanations can be understood with some effort and questioning	**understandable, to the point, can be one-way**	understandable, to the point and can be convincing	understandable, to the point, can be convincing, involves others in communication	B
Technical skills	needed explanations for execution of the tasks	demonstrated skills while help was needed for execution	**could work independently**	contributes as an equal teammember	brings new solutions and develops competences	B
Teamwork	Does not demonstrate ability to work in a team nor make a team	Works well together with other people	**Involves, if triggered by supervisors, the right people in the project**	Involves the right people in the project	Templayer, in control of the project, potentially a leader	B

The designed rubrics are used as an assessment tool to assess the solving-problem strategy of the students, and to compare the assessment by the company problem owners with that of the teachers.

5 RESULTS

5.1 Analysis of physics engineering steps in problem solving

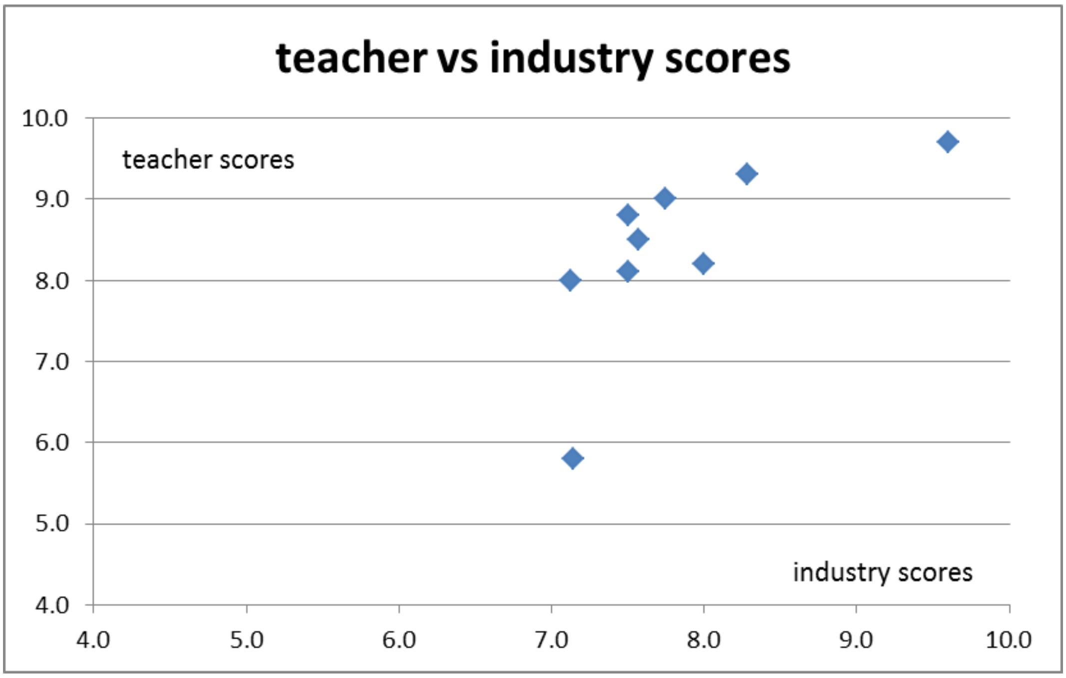
In order to analyse students' abilities in problem solving we developed criteria that we applied in the assessment of reports. The criteria consisted of the problem description, the description of the physics system, the mathematics formula used in the problem-solving approach and simulations, the rough estimation, the verification models, the validation models with external data, the analysis of the data and conclusions, the test of hypothesis, the graphical representation and the different chosen parameters, the quality of the model analysis, and finally, the problem-oriented approach. In *Table 3*. we present the results of students' group assessment. From these results we deduce that there are no major constraints identified in terms of prior knowledge required to start-up this course, the assignments or to conduct the simulations. Furthermore, the use of numerical methods in problem solving has not been either an issue of concern as elements such as the back of an enveloped have been properly applied.

Table 3. Score list of the teachers following the rubrics in **Error! Reference source not found.**

problem description	physics describing the system *1*	Mathematical formula describing the physics of the simulation *1*	a rough estimate *1*	verification of simulation model by assessing the mesh	validation of the model with external data or knowledge *1*	separates observed data from analysis and conclusions	draws conclusions from analysis *1*	be open to test a hypothesis, a critical attitude *1*	graphical representation, choice of axis/parameters *1*	Quality of model analysis and execution, credibility of the solution *1*	Problem oriented approach		**Rubric final assignment and total score**	
The problem is stated in the introduction of the report including the context behind the need	A description is given of the phenomena which are to be modelled with a reasoning for the expected relevance	For every term in the differential equation the meaning of the selected terms is given supported by reasoning	Back-of-the-envelope estimation is given for the critical parameters in the model system	Includes simulation results for three different mesh densities and judges the effect on simulation results	Comparison with expectations from estimation, and data or known behaviour	states given data with a discussion of observations, separately from analysis or conclusions	comes with careful conclusions from modelling analysis	hypothesis is validated by observing the outcome of the test and used to improve the model while showing understanding of the underlying problem	graphs and figure captions are insightful and speak for itself	The model shows relevant features which match expectations qualitatively and quantitatively	The report gives a conclusion based on the modelling results, creating insight for the problem owner	1st assignment (40%)	**final assignment (60%)**	**total score**
8	8	10	10	10	10	8	8	8	8	8	6	8	8.50	8.30
8	8	10	10	10	10	8	8	8	8	8	6	8	8.50	8.30
8	8	10	10	10	10	8	8	8	8	8	6	8.5	8.50	8.50
8	10	10	8	8	3.5	8	8	8	8	6	10	6.875	7.96	7.53
8	10	10	8	8	3.5	8	8	8	8	6	10	7	7.96	7.58
8	10	10	8	8	3.5	8	8	8	8	6	10	7.375	7.96	7.73
10	8	8	8	1	6	6	6	1	6	3.5	6	6.25	5.79	5.98
												6.375		
10	8	8	8	1	6	6	6	1	6	3.5	6	8	5.79	6.68
10	10	8	8	10	6	8	8	8	10	6	6	6.875	8.17	7.65
10	10	8	8	10	6	8	8	8	10	6	6	7.875	8.17	8.05
10	10	8	8	10	6	8	8	8	10	6	6	9.5	8.17	8.70
10	10	10	10	10	10	8	8	8	8	10	10	7.5	9.33	8.60
10	10	10	10	10	10	8	8	8	8	10	10	7.875	9.33	8.75
10	10	10	10	10	10	8	8	8	8	10	10	8	9.33	8.80
10	10	8	10	8	8	8	10	8	8	10	10	8.5	9.00	8.80
10	10	8	10	8	8	8	10	8	8	10	10	8.5	9.00	8.80
10	10	8	10	8	8	8	10	8	8	10	10	8.5	9.00	8.80
10	10	10	10	10	10	10	10	8	8	10	10	6.375	9.67	8.35
10	10	10	10	10	10	10	10	8	8	10	10	9	9.67	9.40
10	10	10	10	10	10	10	10	8	8	10	10	9.5	9.67	9.60
10	10	10	10	10	1	6	8	6	6	10	10	9.00	8.08	8.45
10	10	10	10	10	1	6	8	6	6	10	10	9.00	8.08	8.45
10	10	10	10	10	1	6	8	6	6	10	10	9.5	8.08	8.65
8	10	10	10	6	10	8	8	8	8	10	10	7.25	8.83	8.20
8	10	10	10	6	10	8	8	8	8	10	10	7.875	8.83	8.45
8	10	10	10	6	10	8	8	8	8	10	10	9	8.83	8.90

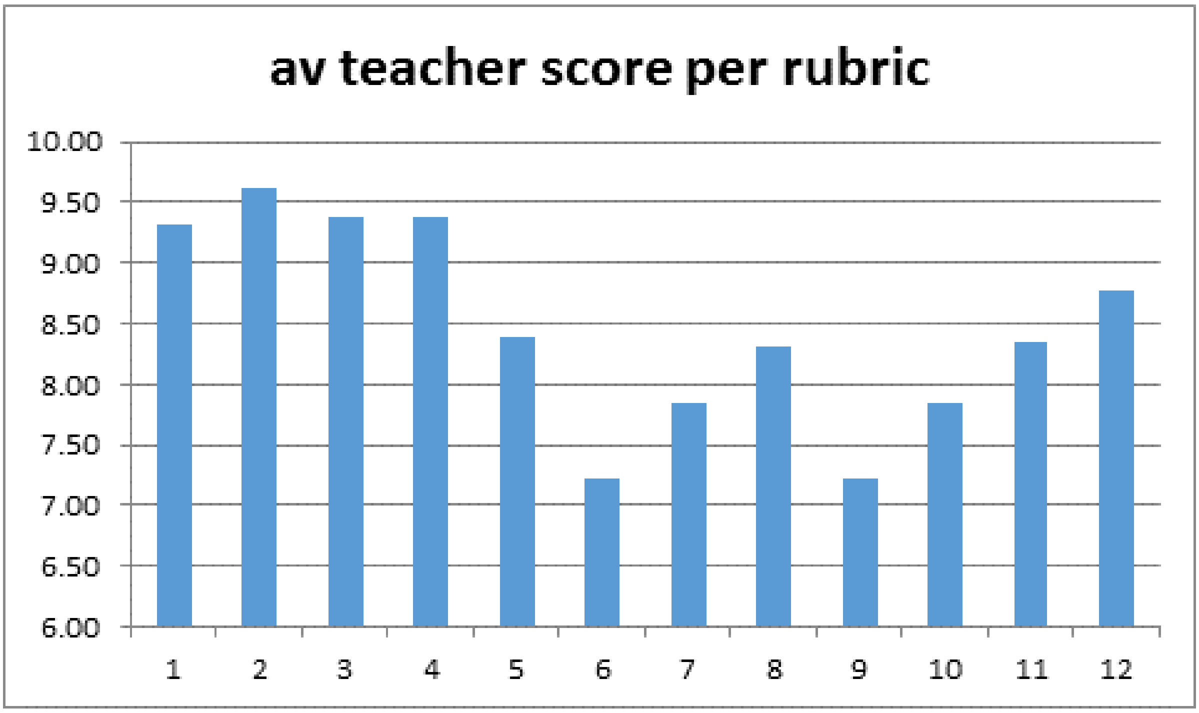
The rubrics are in columns, the students form the lines. The first assignment, boiling the egg, is an individual assignment. The 2nd assignment is executed in teams. The table contains all scores of the teachers for each student, for the 2nd assignment. Behind this is the column with the individual scores for the 1st assignment which weighs for 40%. Next, the total scores for the 2nd assignment are given, weighing for 60% of the total score. The last column gives the total score. One team member dropped out for the 2nd assignment and left the course. In *Fig. 4* we present the scores by company vs teacher using rubrics in Table 1 and 2 respectively.

Fig. 4 Scores by company vs teacher using rubrics in Table 1 and 2 respectively



The results indicate that the scores correlate strongly even though an offset occurs. Following these results, we observe that the assessment with rubrics correlates with the appreciation of the problem owner in the industry. However, the criteria ‘teamwork’ cannot be easily assessed by the company problem owner as they are less involved in supervising the team work.

Fig. 5 Average cores by the teachers per rubric



Results in *Fig. 5* indicate that activities regarding the validation of the model with external data remains a problem as students frequently forget to compare the simulation results with the original estimations (rubric 6), and that the students can be more conscious about assessing their own hypothesis (rubric 9), among others. As this concerns the attitude of the students towards assessing the credibility of their conclusions, it are points for further improvement of the course.

Likewise, to appraise students' perceptions on collaboration skills as well as on the development and improvement of programming and modelling skills, we used a Likert 1 to 5 scale questionnaires (1= totally disagree; 5=totally agree). As perceived from the responses students' perceptions are positive in this regard (See *Fig. 6*).

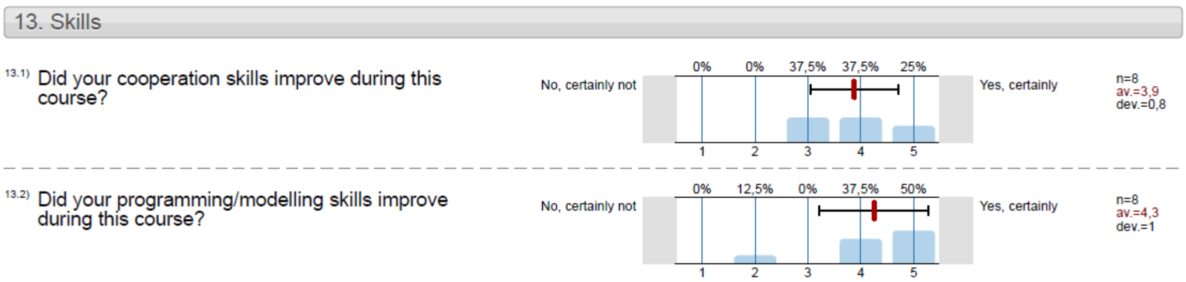


Fig. 6 Students' perceptions regarding cooperation skills and modelling

Furthermore, during the evaluation through focus groups with the students some issues have been identified. First of all, the time for the company assignments was judged to be too short. The students would like to cut the introduction lectures a bit short in order to gain a week for the work on the company assignment. Two students complained that not every team member participated equally. And the blended-platform COMSOL did not work optimally regarding some projects as this e-tool was not capable to simulate certain conditions for the compression of a liquid. This caused considerable delay in the implementation of the project for two teams. Even though a simulation specialist was hired to assist the student teams continuously, the capability of the simulation tool remains a critical issue.

6 CONCLUSION AND DISCUSSION

In this paper the different methods are analyzed for the support of students to acquire engineering skills i.e. use and apply a systematic problem-solving approach to define, implement and validate multiphysics models. The effects of the online tools on students learning to use simulation models for engineering problems result of this first experience. A number of steps are practiced, such as analysis of equations, graphical representation and quantitative analysis; synthesizing and drawing original conclusions in a systematic learning process. Rubrics have been applied for assessment of the work of the students. The feedback from companies and teachers has been compared.

The blended-learning tool COMSOL Multiphysics has served to stimulate students' thinking process in solving engineering problems. Moreover, the problem-based and project-based learning approach has fostered collaborations as perceived by the students.

Comparing the scores of the industry and the teachers regarding students' products shows that the appreciation of the final result by the company problem owners correlates with the judgements of the teachers for each step in the process. We can conclude therefore that the steps in the rubrics to assess the problem-solving strategy are appropriate for this project-based course and should lead to a better result for the companies.

However, it is still early to mention to what extend the new generation of students in engineering physics have made a stand in the industry by this different way of educating physicists. Further studies on academic output to the industry need to be conducted in order to evaluate objectively the level of satisfaction and quality of students to the labour market.

Future improvements of this course consist of more involvement of the industry in the monitoring of the projects, an improved time schedule leaving a week longer for work on the company assignment, a peer review method to intensify the learning process of the students, optimizing self-study through the use of weblectures, and improving the attitude of the students for problem solving. Weblectures provide an additional learning tool to pay attention in detail to already-identified subjects while bridging the gap between the subject matter taught in the lectures, the project-based assignments and simulation work, and finally, the additional subjects provided in the lectures. This didactical method is still new and under construction and we do not present results so far on the effect on the learning process of the students as we do not have reference data yet with non-blended learning.

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