

# ‘Effective teaching and supervision of students through the support of blended- learning tools’

## Final report

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## 1. Short description of the project

With the implementation of the Graduate School (GS) new educational challenges arise. Some implications of the GS ambition is that the classroom composition is more multidisciplinary than ever as the Applied Physics, but more specifically Fusion courses attract students from other TU/e departments and from international universities. The students' intake differs therefore in terms of disciplines and background, prior knowledge and learning styles, but also in profiles, interests and in career perspectives. This requires individual attention to the students.

Furthermore, the supervision of the students during the courses and master research project becomes a crucial trajectory in order to stimulate students work independently but also to become critical towards own work and that of others. This implies supervision on practical, research and design assignments and projects to develop abilities to analyze complex problems, creativity, 'out-of-the-box' and critical thinking expected in our future graduates to solve technological challenges. These supervision forms, rooted in collaborative learning methods (i.e. afstudeerkring<sup>1</sup>, small-group tutorial meetings and intervision, among others) are suitable to integrate in study practices to stimulate creative and critical thinkers, but also to improve the professional skills

The purpose of this project was to experiment with different forms of supervision of students. We also were keen on introducing IT-approaches to activate but also to meet individual needs. In addition, we also wanted to use a blended-learning platform, i.e. Comsol Multiphysics, in order to teach students to simulate by also paying attention to individual needs of the students and differences regarding:

- learning style and pace;
- lacunas and capabilities, such as analysis of equations, graphical representation and quantitative analysis; synthesizing and drawing conclusions.
- prior knowledge: understanding numerical methods.

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<sup>1</sup> Romme, A.G.L., Nijhujs, J.F.G. (2002).

## 2. Objectives and outcomes of the project

Objectives	Products/Deliverables	Outcomes
<p>Upgrade educational methods that allows students to acquire engineering skills i.e. use and apply a systematic problem-solving approach to define, implement and validate multiphysics models</p>	<p>Introduction of COMSOL Multiphysics, As an online classroom kit. This allows students to develop experiments and carry out simulations.</p> <p>Dissemination through international conference</p>	<ul style="list-style-type: none"> <li>• Developed <i>Physics of Engineering Problems</i> (PEP) master course</li> <li>• Students have learned modelling and simulating of engineering problems and a systematic approach to define, implement and validate multiphysics models.</li> <li>• Target: Students from different departments joined the course. Accomplished: Only one student from Mechanical Engineering department joined the course.</li> <li>• Upgraded the current educational and didactical methods (i.e. supporting learning with online teaching, COMSOL Multiphysics, and enhance self-study with weblectures and pencasts, etc.) of the course <i>Physics of Engineering Problems</i>;</li> <li>• Supervised students' progress by first identifying deficiencies and lacunas in prior knowledge at the beginning of the course</li> <li>• Stimulated learning from peers by reviewing the work of the fellow students' assignments.</li> </ul>
<ul style="list-style-type: none"> <li>• To integrate blended-learning in Science and Technology of Nuclear Fusion master courses (<i>Magnetic Confinement and MHD for fusion plasmas - 3MF110-Fusion Reactors: extreme materials and intense plasma wall interaction - 3MF120</i>)</li> </ul>	<p>IT tools (weblectures, screencast or pencasts) were introduced to surmount students' deficiencies and individual needs</p>	<ul style="list-style-type: none"> <li>• Series of weblectures were recorded tackling conceptual understanding</li> <li>• New IT method is introduced to record screencasts with Adobe captivate</li> </ul>

<ul style="list-style-type: none"><li>• To integrate new supervision methods based on small-group tutorials &amp; intervision for master students carrying out master courses and research within the Science and Technology of Fusion and PEP study program.</li></ul>	<ul style="list-style-type: none"><li>• Abstract method</li><li>• Master ring</li><li>• Peer review master students</li></ul>	<ul style="list-style-type: none"><li>• A supervision method is in place</li></ul>
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### 3. Evaluation innovations

#### 3.1. Evaluation supervision methods: Abstract method

##### Description of the science lunch as it was: SL1.0

The fusion MSc programme has the 'science lunch' (SL) as a regular educational programme item. It is a meeting during lunchtime that takes place 2-3 times a week, in which all students and staff take part. Students in the programme are told that they are expected to take part, but there is no obligation to be there every time, nor do we register attendance. There are no ECTS associated with participation in the SL. On the other hand, the SL is considered to be very important because it is a place where students develop their ACQA competences, both domain specific (they learn about fusion from all the talks and discussions) and generic (scientific discussion, forming a judgment, presenting science,..).

In the SL, it is almost always a student who gives a presentation. Usually this is about their internship or graduation project. The presentation can be early in the project: to discuss the plan; midway: to spar with the audience about the results or problems encountered; or at the end, by way of final report. Also PhD students give presentations in the SL. The audience often includes remote participants through a skype connection.

The SL1.0 has a fixed pattern: Very brief introduction of the speaker by his/her supervisor; then 12' presentation (sharply times – this is part of the training). Followed by 20' of discussion, in which the rule is that students have priority over staff.

The SL starts at 12:45 and ends at 13:30. The timing is chosen such that it does not conflict with lecture hours.

The science lunch was introduced years ago, but its frequency increased with the increasing number of fusion students to reach the present 2-3 SL/wk. The high frequency is beneficial, because it means that everyone knows: lunchtime means SL time. The invitations are sent out automatically to all students and staff. Since January 2016, the invitees also include the fusion staff at DIFFER, and the SL is occasionally organized at DIFFER, with the aim to improve the exchange between TU/e and DIFFER.

##### The SL1.0 was ok, but we felt it could be improved

The SL1.0 as it was worked reasonably well. But we felt that we often had to drag the questions out of the students after the talk, the quality of the discussion was often not so good (it often seemed the students didn't really grasp the message of the talk), and the atmosphere did not have quite buzz or excitement that we wanted to see. Also, we noticed that first year MSc students often forfeited, or did not think this was useful for them, or felt they were too busy.

Nonetheless, the SL1.0 served a purpose in that it did succeed in sharing within the group what everybody was working on.

In a brainstorm-style discussion with Education Policy Advisor about the SL1.0 and how it could be improved, we made the following observations:

- There is a need to make the SL more exciting
- There is a need to improve the quality of the questions
- We realized that the SL we should emphasize the fact that the SL is a training for the audience as much as for the speaker.
- We realized that with proper instruction we could train the speaker with less effort from our side.

We came up with three simple, easy-to-implement measures that would address all of these points. This forms the pilot described below.

### **The pilot: Add Abstract; Prediscussion; Chocolate bar**

The pilot consists of the following three adjustments that together define SL2.0:

**1. Abstract.** The speaker is asked to provide a 10 line abstract at least a day in advance. The aim is to add the educational element 'learning to write a good abstract', as well as to provide the basis for element 2: plenary prediscussion of the abstract. The speaker is provided with guidelines for the writing of abstracts.

**2. Plenary prediscussion.** Before the presentation, i.e. the first 5' of the meeting, the abstract is displayed on the screen and the speaker is asked to leave the room; the audience is then asked to discuss the abstract – neighbours forming small groups – during a few minutes, after which the meeting chair makes a round of the groups, asking them what they intend to ask after the talk. The audience is asked 'after reading the abstract: what is unclear, what do you expect to be explained in the talk, is it clear what the topic and research question is?'

**3. The chocolate bar competition.** At the end of the meeting, the speaker has the privilege to decide which question was most relevant, or deep, or helpful and award a bar of chocolate to the person who came up with that question. It is also possible that the audience collectively decides that the talk was so clear and the handling of the questions so expertly done, that the chocolate should go to the speaker.

The pilot was to be run 10 times before evaluation. The evaluation will consist of

- observations by the organizers (this report)
- report by Education Policy Advisor, who participates in three SL2.0 sessions
- interviews with a few students (audience) by the Education Policy Advisor. (we decided against questionnaires, as the students are already overfed with those).
- Interviews with presenters, both students and a guest scientist

Already after a few editions of SL2.0 it was decided to make this the new standard and abandon the SL1.0 altogether.

## Evaluation

### Overall description: what changed in the experience

Overall, we should say that SL2.0 is a resounding success. Already during the prediscussion the interest of the audience is much higher than it was before, during the talk the attentiveness seems to be significantly higher, and the quality of the discussion has improved dramatically: not only do we not have to drag questions out of the students – they are now eager to pose their questions, take part in the discussion, there are always many more questions than we can accommodate in the 20' available. A guest scientist who gave a talk in the SL (and was treated like any other speaker, including the request to step out of the room for a few minutes) remarked that she was surprised by the depth of the questions and that the discussion after her talk was the best she had ever had, including that in many talks for specialists).

Another important observation: there is a general sense of excitement, the SL is perceived as a not-to-be-missed event, and the participation has increased so much that we have had to move to a larger meeting room.

### Experience for the audience, role of the abstract, and role of the prediscussion

We feel that the central element of the improved SL is the plenary prediscussion of the abstract, i.e. the discussion in groups leading to the formulation of questions. The abstract, while also serving the goal of training the presenter to write abstracts, really is only there to enable this plenary discussion.

We observe that the prediscussion immediately creates a buzz, it raises the interest of the students and the atmosphere becomes excited, animated. This atmosphere then lasts throughout the meeting.

This is just our experience as organisers. We should compare this to the interviews of the students. But the enthusiasm for participation in the SL is at least a good sign.

### Experience for the speaker

We have given the speakers instruction for the writing of an abstract and the preparation of a good talk. And the supervisors coach the students, give feedback on the slides, and encourage them to practice the talk with a few fellow students. Moreover, the students frequently take part in SL meetings in which also the presentation skills are commented on, so they learn also by seeing other do it well, or badly.

The question is how the SL2.0 differs from SL1.0 for the speaker. The abstract is a new and useful element. The (preparation of) the talk is not different. In our estimation, the biggest difference is that the audience is much more attentive and alert during the presentation, and that the discussion is of a very high level. This is a stimulating and also helpful experience for the speaker, who gets more out of the talk in terms of feedback and ideas.

### **Role of the chocolate bar**

Although introduced as a fun element, the chocolate bar competition actually does seem to help in creating an atmosphere of friendly competition and generally a good mood in the group.

### **Overall conclusion and recommendation**

In conclusion, the SL2.0 has turned the SL1.0 into a much more effective educational activity, and one that is more enjoyable, too. This has come at no additional effort of the staff at all. It has really surprised us how much better the SL works after making such simple adjustments. It works so well that one asks why the same principle isn't applied to other meetings, such as colloquia.

## **3.2. Evaluation master ring**

### **Set-up of the maser ring**

The goal of the master ring was to have students to enhance efficiency in the supervision of students by introducing master rings in the form of peer review. Students, therefore, gather together to provide feedback to each other's' chapters of the master thesis before these are revised by the supervisor.

The master students taking part in the master ring were invited for an instruction meeting in which the following topics were addressed:

- Context and theoretical insights of master ring (See also appendices 2 and 3)
- Objectives of the mater ring
- Basic peer review and feedback methods
- Approach and agreements to work together with students in groups
- Guiding questions for the revision of master thesis chapters

Although the project team suggested to have 3 groups of ~5 students, it turned to be man-power intensive and probably not efficient. It was finally decided to have 5 groups of up to 3 students.

In contrast to the master ring model in Maastricht in which students follow an agenda and they divide the tasks to gather together with the teacher/supervisor, we had the students to arrange themselves and gather without the supervision of the teacher. It was also agreed upon that the supervisor will join ad hoc some of the meetings. In addition, a clear requirement was that before the documents are sent to the supervisors for revision, they have to be discussed/peer reviewed before with the group members of the master ring.

## Evaluation

There have been two evaluations during the period in which the students have to write different parts of the thesis. We reviewed the following based on these evaluation questions:

Does the master ring help to?

- To enhance quality & efficiency of supervision
- To enhance students' supervision/peer review skills
- To provide additional supervision & feedback
- To stimulate collaborative learning
- To solve common problems arising during supervision process, e.g. unclear chapters, missing information, imprecise presentation of data, etc.
- To promote and facilitate exchange of knowledge & experience among students
- To share problems & look for common solutions
- To avoid delay

Students were positive about this supervision method. As advantages they mentioned:

- *It helps to learn to be critical about own work and these by others.*
- *The feedback helps to improve some elements of the chapter which are not clear for the reader, for instance, tables, or graphs, or the content, etc.*
- *Students also learn from each other to implement the experiments.*
- *Students feel comfortable as they manage to organize themselves instead of having strict rules for the meetings.*
- *The guiding questions were used at the beginning and they were useful. However, students used the guiding questions any more. No need.*

There are some other aspects that could not be evaluated at that time such the efficiency and quality of supervision because the supervisors had not received so far any chapter.

The students made as remark that *it is sometime difficult to peer review each others' chapters if not all students are at the same path in writing.*

Some issues of attention were to arrange better the frequency of the meetings.

*During the second evaluation, we addressed the same questions to the students. They students seem to value this supervision approach and it helps to give continuity to what it is agreed upon.*

*Students believe that the feedback from the peers helps to improve the text and documents presented to the supervisors.*

*Surprisingly, the students didn't identify any more a problem the fact that they are sometimes in different phases of the master thesis writing part. The goal is to peer review regardless the phase of the project they go through.*

### Lessons learned:

- This method works best with a small group of students.
- The method works positively when the students are motivated.
- Instruction on the method and how to give feedback supports

### 3.3. Evaluation Peer review at Applied Physics

Within the Applied Physics department we initiated a peer review group. The peer review approach consists of five students who come together four times in one year during the implementation of the industry internship project.

The peer review and intervision method followed was based on:

- Student presents context project and formulates the challenge;
- Other students ask open questions in order to define better what the problem or challenge is about;
- Student, the holder of the problem/challenge, narrows down the problem/identify better the core of the challenge;
- Students suggests potential solutions.

The students followed a short instruction on peer review prior to the beginning of the project.

The set-up of the meetings is based on short presentations regarding:

- You and your project, each presents the project topic in 5 slides / 10 minutes
- You and your project: present progress on the definition phase. Specifications and project phases
- Agreements and stakeholder communication / specification process / risk analysis
- Making choices: ideation and selection
- Discussing hurdles, and conclusions

### Lessons learned:

- The peer review sessions have taken place already two times. There are still two to go by the time this report is written. It is difficult at this stage to draw conclusions. However, the initial impressions by the students is that this is a useful activity as they are able to share common issues that can help others to find solutions for problems.

### 3.4. Evaluation Physics of Engineering Problems course

The *Physics of Engineering Problems (PEP)* course is part of the graduate Applied Physics (AP) university master program. Within this course we tried 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 allows students to use phenomena in steps by analyzing the questions and making estimations from a mathematical perspective.

To support the students to learning through simulations we introduced 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. The students used this online platform to simulate both in individual and group project assignments.

## Evaluation

The effects of the online tools on students learning to use simulation models for engineering problems resulted in some gains. 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.

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.

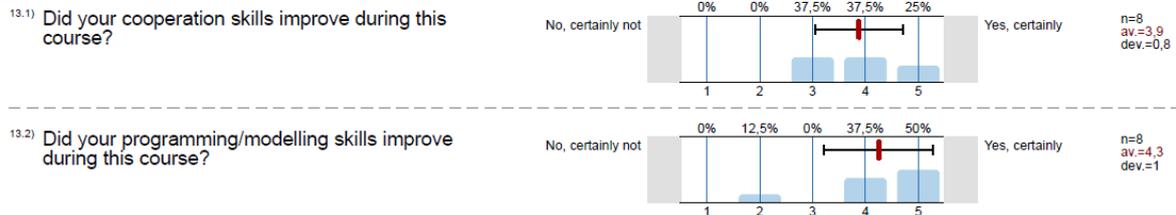
Rubrics have been applied for assessment of the work of the students and the feedback from companies and teachers has been compared. Comparing the scores of the industry and the teachers regarding students' products indicate that the appreciation of the final result by the company problem owners correlates 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 extent 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.

### 13. Skills

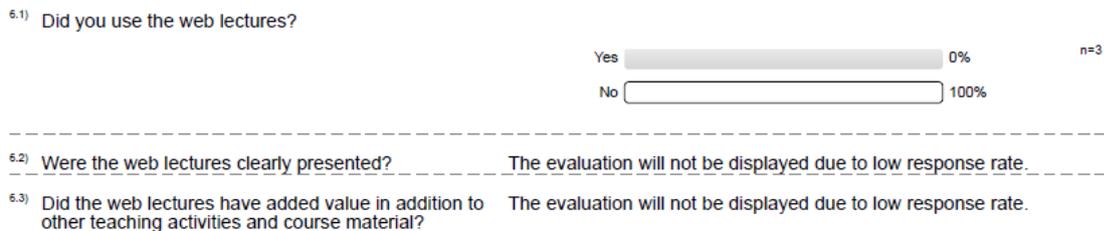


## 4. Evaluation of the innovation in Fusion master courses

### Fusion Reactors: extreme materials and intense plasma wall interaction (3MF120) (MSc. Science & Technology of Nuclear Fusion) courses

The objective to introduce weblectures in the master courses of the Fusion program was to address difficult concepts and theoretical insights that are not tackled during the lectures extensively but are relevant parts of the course. Within this course two weblectures have been recorded, including a guest lecture from DIFFEER, a TU/e research center. In addition, a different towards teaching approach, i.e. flipped the classroom, was used in some lectures. This in order to interact during the lectures by asking relevant questions linked, sometimes, to the content of the weblectures. Although we tried to evaluate this method, the response (n=3 out of N=26) is really low to be able to analyze the results.

### 6. Video lectures/web lectures



### Magnetic Confinement and MHD for fusion plasmas (3MF110)

The goal to introduce weblectures or screencasts in this course was to address deficiencies in prior knowledge and differences in background (physics and engineering) and learning styles.

There is only one screencast recorded for this course which has not be tested yet with students. The method used for the screencast is Adobe Captivate.

## Appendices

### Appendix 1 – Abstract approach for science lunches

#### How to Write an Abstract for the Undergraduate<sup>2</sup>

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##### What is an abstract?

An abstract is a one-paragraph summary of a research project. Abstracts precede papers in research journals and appear in programs of scholarly conferences. In journals, the abstract allows readers to quickly grasp the purpose and major ideas of a paper and lets other researchers know whether reading the entire paper will be worthwhile. In conferences, the abstract is the advertisement that the paper deserves the audience's attention.

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##### How does an abstract appeal to such a broad audience?

The audience for this abstract covers the broadest possible scope--from expert to lay person. You need to find a comfortable balance between writing an abstract that both shows your knowledge and yet is still comprehensible--with some effort--by lay members of the audience. Limit the amount of technical language you use and explain it where possible. Always use the full term before you refer to it by acronym [DNA double-stranded breaks (DSBs), for example]. Remember that you are yourself an expert in the field that you are writing about--don't take for granted that the reader will share your insider knowledge.

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##### What should the abstract include?

Think of your abstract as a condensed version of your whole project. By reading it, the reader should understand the nature of your research question. Like abstracts that researchers prepare for scholarly conferences, the abstract you submit for the Undergraduate Research Conference will most likely reflect work still in progress at the time you write it. Although the content will vary according to field and specific project, all abstracts, whether in the sciences or the humanities, convey the following information:

- The purpose of the project identifying the area of study to which it belongs.
- The research problem that motivates the project.
- The methods used to address this research problem, documents or evidence analyzed.
- The conclusions reached or, if the research is in progress, what the preliminary results of the investigation suggest, or what the research methods demonstrate.
- The significance of the research project. Why are the results useful? What is new to our understanding as the result of your inquiry?

Whatever kind of research you are doing, your abstract should provide the reader with answers to the following questions: What are you asking? Why is it important? How will you study it? What will you use to demonstrate your conclusions? What are those conclusions? What do they mean?

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##### Stylistic considerations

The abstract should be one paragraph and should not exceed the word limit. Edit it closely to be sure it meets the Four C's of abstract writing:

- Complete — it covers the major parts of the project.
- Concise — it contains no excess wordiness or unnecessary information.
- Clear — it is readable, well organized, and not too jargon-laden.

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<sup>2</sup> Retrieved on February 23<sup>rd</sup>, 2016 and adapted from <https://urc.ucdavis.edu/conference/write.html>  
Research Scholarship and Creative Activities Conference

- Cohesive — it flows smoothly between the parts.

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### The importance of understandable language

Because all researchers hope their work will be useful to others, and because good scholarship is increasingly used across disciplines, it is crucial to make the language of your abstracts accessible to a non-specialist. Simplify your language. Friends in another major will spot instantly what needs to be more understandable. Some problem areas to look for:

- Eliminate jargon. Showing off your technical vocabulary will not demonstrate that your research is valuable. If using a technical term is unavoidable, add a non-technical synonym to help a non-specialist infer the term's meaning.
- Omit needless words—redundant modifiers, pompous diction, excessive detail.
- Avoid stringing nouns together (make the relationship clear with prepositions).
- Eliminate "narration," expressions such as "It is my opinion that," "I have concluded," "the main point supporting my view concerns," or "certainly there is little doubt as to. . . ." Focus attention solely on what the reader needs to know.

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### Before submitting your abstract

- Make sure it is within 150-200 words or 10 lines max. (Over-writing is all too easy, so reserve time for cutting your abstract down to the essential information.)
- Make sure the language is understandable by a non-specialist. (Avoid writing for an audience that includes only you and your professor.)

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### Example

#### Multimedia Risk Assessment of Biodiesel - Tier II Antfarm Project

Significant knowledge gaps exist in the fate, transport, biodegradation, and toxicity properties of biodiesel when it is leaked into the environment. In order to fill these gaps, a combination of experiments has been developed in a Multimedia Risk Assessment of Biodiesel for the State of California. Currently, in the Tier II experimental phase of this assessment, I am investigating underground plume mobility of 20% and 100% additized and unadditized Soy and Animal Fat based biodiesel blends and comparing them to Ultra Low-Sulfur Diesel #2 (ULSD) by filming these fuels as they seep through unsaturated sand, encounter a simulated underground water table, and form a floating lens on top of the water. Thus far, initial findings in analyzing the digital images created during the filming process have indicated that all fuels tested have similar travel times. SoyB20 behaves most like ULSD in that they both have a similar lateral dispersion lens on top of the water table. In contrast, Animal Fat B100 appears to be most different from ULSD in that it has a narrower residual plume in the unsaturated sand, as well as a narrower and deeper lens formation on top of the water table.

*This webpage was based on articles written by Professor Diana Strazdes, Art History and Dr. Amy Clarke, University Writing Program, UC Davis. Thanks to both for their contributions.*

## Appendix 2 – Master ring

### Peer supervision and review in writing Master rings<sup>3</sup>

#### Introduction:

*Master students' rings* is a supervision model from Maastricht University by which students share the responsibility for the supervision and assessment of these thesis projects. The objective of supervising thesis rings is to enhance the quality and efficiency of supervising activities. This educational instrument is explicitly aimed at supervision and at thesis writing itself, and students come to be supervised, and additionally act as co-supervisor of other students. The thesis ring is, therefore, an extension of the supervisor (p. 4). In this case, we also want to introduce peer review as a method to enhance efficiency in the supervision, quality of supervision, and maximize feedback.

#### Purpose of the master ring:

- Implement an efficient method to maximize the quality of the thesis
- Enhance students' supervision skills
- Solve common problems arising during the supervision process, e.g. unclear chapters, missing information, imprecise presentation of data, etc.
- Promote and facilitate the exchange of knowledge and experience among students.

#### Method:

- Students get two roles: the thesis writer and the one who is being supervised, and the co-supervisor of peers.
- Meetings are organized around themes/sections of the master thesis report: e.g. Chapter 1: Introduction; Chapter 2: Research questions, etc.
- Students send before the meeting each other's' chapters, of pieces of documents, e.g. results of an experiment.
- Students read carefully the documents of the peer students. Based on the document '*Guidelines and criteria to write master thesis*', students prepare comments, jot down questions and prepare a review and feedback. This will assure quality in the process.
- Appointments and clear deadlines need to be agreed for the submission of chapters and documents in order to provide sufficient time for reading and reviewing.
- The final judgment and remarks on the whole master thesis report are made following the Rubric on Writing master thesis.

<sup>3</sup> Romme, A.G.L. & Nijhuis, J.G.H. (2000). Collaborative learning in master rings.

[https://www.researchgate.net/publication/259145056\\_Collaborative\\_Learning\\_in\\_Thesis\\_Rings](https://www.researchgate.net/publication/259145056_Collaborative_Learning_in_Thesis_Rings)

Bean, John C. (2001). *Engaging Ideas: The Professor's Guide to Integrating Writing, Critical Thinking, and Active Learning in the Classroom*. San Francisco: Jossey-Bass.

Gottschalk, Katherine and Keith Hjortshoj (2004). "What Can You Do with Student Writing?" In *The Elements of Teaching Writing: A Resource for Instructors in All Disciplines*. Boston: Bedford/St. Martin's.

Millis, Barbara J. (2002). "Enhancing Learning-and More! Through Collaborative Learning. IDEA Paper 38. The IDEA Center.

[http://www.theideacenter.org/sites/default/files/Idea\\_Paper\\_38.pdf](http://www.theideacenter.org/sites/default/files/Idea_Paper_38.pdf)

Nilson, Linda. (2003). "Improving Student Peer Feedback." *College Teaching*, 51 (1), p. 34-38.

**Guidelines for Peer review at academic level<sup>4</sup>**

- Before you even make your first comment, read the document all the way through.
- Make sure you leave enough time for you to read through, respond, and for your peer to edit his/her document with your comments before any deadlines.
- Point out the strengths as well as the weaknesses of the document.
- When providing comments or asking questions, make sure your comments help the peer-student(s) in the master ring:
  - to analyze and structure ideas logically;
  - to Interpret – clarify meaning through theories/approaches/methods;
  - to explain – justify results, arguments or procedures;
  - to evaluate – assess arguments;
  - to infer – draw conclusions.
- Offer suggestions, not commands.
- Editorial comments should be appropriate and constructive. Be sure that your comments are clear and text-specific so that your peer will know what you are referring to (for example, terms such as "unclear" or "vague" are too general to be helpful).
- As a reader, raise questions that cross your mind, points that may have not occurred to your peer author.
- Try not to overwhelm your peer with too much commentary. Follow the '*Guidelines and criteria to write master thesis*' to give feedback and issues you are supposed to address.
- Be careful not to let your own opinions bias your review (for example, don't suggest that your peer completely rewrite the paper just because you don't agree with his/her point of view).
- Reread your comments before passing them on to your peer. Make sure all your comments make sense and are easy to follow.
- Avoid turning your peer's paper into your paper.
- Be respectful and considerate of the writer's feelings.

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<sup>4</sup> <https://serc.carleton.edu/sp/library/peerreview/tips.html>

## Appendix 3 – Guiding questions ‘Master ring’

### Writing master thesis skills: Structure for Writing master thesis<sup>5</sup>

<b>Guidelines and criteria</b>
<p><b>Introduction:</b> (this section depends also on your preliminary literature review). This section includes:</p> <ul style="list-style-type: none"> <li>• Set the context: Overview of problems and issues leading up to your statement of the problem/research question/sub-questions.</li> <li>• The background of the topic area: <ul style="list-style-type: none"> <li>• Broad statement indicating the overall purpose of the research</li> <li>• <u>Outline:</u> breakdown into logical research steps &amp; definition of research plan.</li> </ul> </li> </ul> <p><u>Example (be concise):</u></p> <ul style="list-style-type: none"> <li>- <i>Energy/Climate problem</i> <ul style="list-style-type: none"> <li>- <i>fusion as one of the few options (to save the world)</i> <ul style="list-style-type: none"> <li>- <i>open issues in fusion</i> <ul style="list-style-type: none"> <li>- <i>the particular issue you want to focus on, e.g. PSI.</i></li> <li>- <i>a particular approach to this issue, e.g. Liquid Lithium</i></li> </ul> </li> </ul> </li> </ul> </li> </ul> <ul style="list-style-type: none"> <li>• Summary of recognized facts and information in relevant scientific literature (reference literature).</li> <li>• Description of the approach</li> <li>• Sketch the research question(s), hypothesis which are central to this study</li> <li>• Description of the procedure you used in conducting your review of the literature</li> <li>• <u>Structure of the report:</u> Mention what sections will be included in the chapters. Organization of the chapters, e.g. in a research form? topically? chronologically?, etc.</li> </ul> <p><b>Guiding questions:</b></p> <ul style="list-style-type: none"> <li>▪ Why is this an important topic to address in this scientific research thesis? What is the problem?</li> <li>▪ What has been the scientific development of the topic?</li> <li>▪ Have there been significant investigations, studies, or reports concerning the topical area?</li> <li>▪ What are the different points of view within the body of knowledge on this topic?</li> <li>▪ What is the current status/focus of the area of your interest? Why?</li> <li>▪ What are the major outstanding concerns in the general area?</li> <li>▪ What direction should my study take based on my review of the literature?</li> </ul> <p>*After writing the Introduction at the beginning of your master thesis period, you may look at this section again at the end. Some parts may be added, such as for instance, a summary of relevant obtained experimental results and the methods used and how these are interpreted.</p>
<p><b>Literature review: Preliminary problem statement &amp; relevance of the study</b><sup>6</sup>:</p>

<sup>5</sup> Adapted from and retrieved on Feb. 23<sup>rd</sup>, 2016 and adapted from [http://www.sei.cmu.edu/sepg/na/2012/upload/SEPG-NA-2012\\_Abstract-Review-Guidelines.pdf](http://www.sei.cmu.edu/sepg/na/2012/upload/SEPG-NA-2012_Abstract-Review-Guidelines.pdf).

<sup>2</sup> Adapted from and retrieved on Feb. 25<sup>th</sup>, 2016 [https://edtech.boisestate.edu/docs/advising/thesis/Thesis\\_Writing\\_Guidelines.pdf](https://edtech.boisestate.edu/docs/advising/thesis/Thesis_Writing_Guidelines.pdf)

**Literature review:** is a careful examination of the state-of-the-art within the concern area of study. It is essential to discover what is already known about your topic/area and what kind of information can be essential to shed light in your research. Be critical in selecting/rejecting the literature.

- This section concerns also the justification for the selection of the topic. This includes an outline of the context and field of study, resulting in a concise problem statement. The scientific and empirical or theoretical relevance of the study is addressed in this section.
- Describe implicitly and explicitly the scientific relevance of the selected research topic.
- Present a summary of the preliminary investigation around the problem framed in substantial knowledge base in order to pose the concrete issues that will be researched, including theoretical and empirical literature review of material.
- Explain the theoretical framework which give direction to the overall research/thesis work.
- Describe the main theoretical categories/concepts, along with their relations to the substantive areas under investigation.
- What are the probable benefits of the research in this specific field?
- Does the theoretical framework provide an adequate argument based on existing theories and concepts?
- Is the theoretical framework connected to the scientific objectives/ support to answer the research questions?

**Guiding questions:**

- What is my research question? What is known about my subject? What is my original idea within this field?
- Are there any gaps of knowledge of my subject? Have these gaps been identified by other researchers or professionals in the field?
- Is there a consensus on relevant issues or is there significant debate?
- What are the various positions/theories, etc? With the selection of this literature do I have relevant information to frame the theories, approaches or method for my research?
- What new information will the research produce which is not already known?

**Scientific objective(s) and research questions:**

- This section clearly states the scientific objectives of the research project contributing to the theoretical reconstruction of the topic at stake. Essential is that scientific objectives of the research have a clear and explicit focus: “to evaluate”, “to explore”, “to determine”, “to verify”, etc.

**Guiding questions:**

- Is the ‘original idea’ mentioned?
- Is the research question directly related to the review of the literature?
- Does the question help clarify the problem statement?
- Is it possible to misinterpret the question?/Is the objective specific and clearly stated?
- Is the objective directly related to the review of the literature?
- Does the research question discuss the main scientific/engineering issues? Example:
  - *‘In order to address the feasibility of this new approach, we have to consider the following issues {heat load, melting point, capillary forces, ....}.’*
- In case of hypothesis: Is each hypothesis clearly stated?/Are the hypotheses testable?
- Does the problem/research question pose significance for the scientific field of fusion?
- Will the problem/research question present data that explains previously unexplained facts?

- Will the problem/research question serve as a point of departure for the study?
- Does the research address an important problem?
- Is the research question concisely mentioned: Example:  
*Research question: assess the feasibility of a plasma-facing component for a fusion reactor based on the concept of a flowing, double-layer liquid metal sheath, capable of taking a steady heat load of 10 MW/m<sup>2</sup> as well as ELM-induced peak heat loads of 1 GW/m<sup>2</sup> during 1 ms pulses*

But before you can state your research question, you'll need to say a few words about the state of the art in the chosen topical field and identify what you plan to add to this.

{'In the literature 3 distinct liquid metal wall concepts are described...(references) ... In another paper, on the cooling of milk tanks in dairy industry, a quite different concept has been introduced in a completely different context. We think that this concept, with suitable adaptations, could be applied to the design of an essentially new, i.e. 4<sup>th</sup>, liquid metal wall concept for fusion applications'}. (just making this up)

#### **Outline research plan/approach/methodology:**

- Outline research plan/approach/methodology: The function of this section is to specify for instance:
  - *lay down the basic design and the parameters that define it;*
  - *set up the theoretical framework that is needed to do your analysis;*
  - *build a set-up in which you can investigate prototypes experimentally;*
  - *design a test protocol that will result in data that will answer your question;*
  - *build a computational model.*
- how the principles of reliability, validity and replicability will be reached.

#### **Guiding questions:**

- Is the plan/approach/method explained appropriate to answer and study the research question empirically?
- Are the concepts, research methods, instruments, etc. described to gather data empirically, assumptions?
- Does the data collection approach supported by solid arguments for the selection of the approach? i.e. sources of information (e.g., pictures, texts, individuals, graphs, etc.); criteria for determining and delineating the sources of information (e.g., how will the experiment carried out, assumptions, expected results, etc. qualitative or quantitative research methods.

#### **Data Analysis/Analysis and reporting on results:**

- Describe all steps for data collection & data analysis: sample, research method and instruments, etc.
- Figures and technical requirements:
  - *Try to make all your figures in a consistent style: same type of axis, same line weight, same fonts, same colour scheme.*
  - *The **font size** in the figure should be comparable to the font in the written text. That would typically be 10-12 pt. Not smaller.*
  - *Make sure that all lines and symbols are distinguishable and defined in the caption*
  - *Importantly: remove all information that is not necessary for your report.*
  - *If you use a figure from an external source: give proper reference. And: you cannot just copy it – that would be an infringement of the copyright. In that case you need written consent from the author or publisher. Alternatively, you can basically redo the figure (several ways to do that – it usually takes not too much time with modern tools). Then the copyright does*

*not apply anymore – but the intellectual property of course still resides with the original author, so you always have to give proper reference.*

**Guiding questions:**

- Is the sample appropriate for the purpose of the study?
- Do the results illustrate clearly the findings?
- Is the data represented in figures/graphs/tables accurate?

**Interpretation and discussion:** of results and findings

**Guiding questions:**

- Have you provided an overview of the significant findings of the study?
- Have you discussed the findings and compared them to existing research studies?
- Have you presented implications of the study for education?
- Have you discussed the applications of your findings?
- How can the results be operationalised into the scientific fusion practice?

**Summary and conclusions**

- This section includes an overview of the study (not of your findings).
- Place the results in the context of the literature: Restate the problem, research questions, hypotheses and a short summary of the procedures you followed in conducting your study.
- Limitations and implications for further research to the study must be discussed by identifying the barriers and constraints students expect in conducting the research.
- In the conclusions: include your statement drawn from findings and mention main result in short.

**Guiding questions:**

- Are the summary, conclusions and recommendations concisely and precisely stated?
- Are the conclusions and recommendations justified by the data gathered?
- Does the study suggest related problems that need to be investigated?
- Are your recommendations data-based and stem directly from the data and the conclusions?

**References**

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## Appendix 4 - Conference paper *Physics of Engineering Problems*

44<sup>th</sup> SEFI Conference, 12-15 September 2016, Tampere, Finland

### **Physicist of the future: Multiphysics simulation models in engineering assignments**

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Keywords: Engineering education, physics, engineering thinking design

### **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 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

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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).

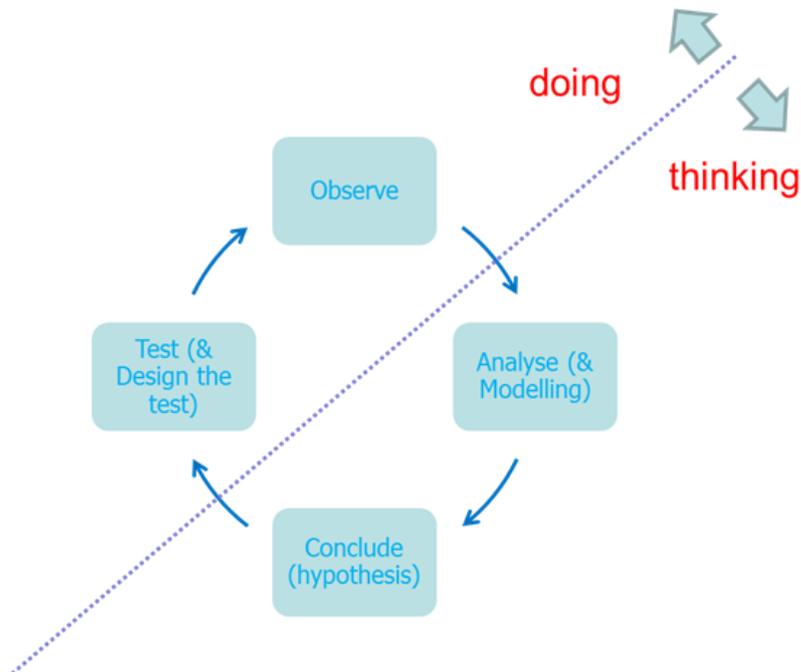


Fig. 1. Four steps in the learning process

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 ( $>65^{\circ}\text{C}$ ) but remaining liquid ( $<70^{\circ}\text{C}$ ) while the egg white (albumen) is already solidified ( $80^{\circ}\text{C}$  to  $100^{\circ}\text{C}$ ). 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 1<sup>st</sup> 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.

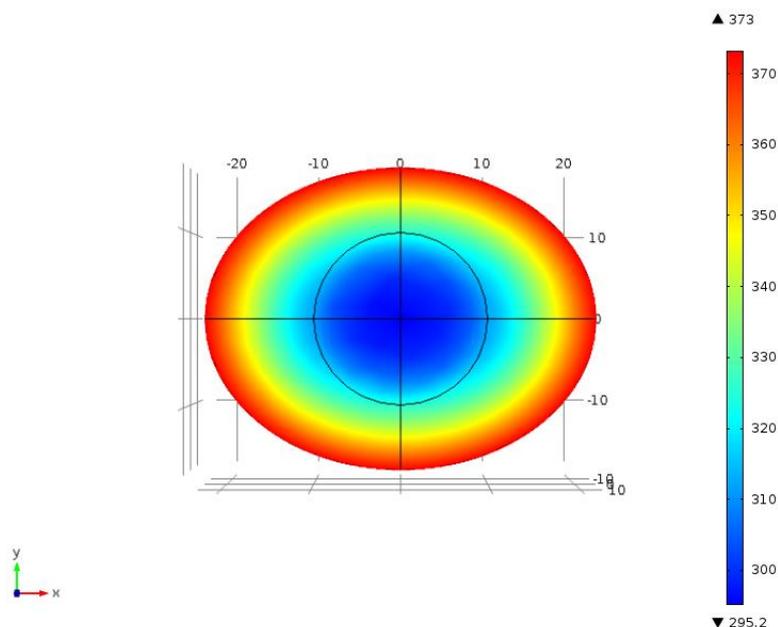


Fig. 3. Egg model by student in boiling water after 360 seconds

## 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		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
	Apply the learning cycle					
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
<b>Dimensions</b>						
<b>Performance, general</b>	Poorly	should have done better	<b>Meets requirements, with some help</b>	Meets requirements	Exceeds requirements	B
<b>Systematic approach</b>	None	needed guidance for most steps	works structured with normal help	<b>works structured independently</b>	works structured by nature	A
<b>Inventivity in problem solving</b>	No surprise	Surprise for laymen	<b>Surprise for peers</b>	Surprise for professionals	Surprise for supervisors	B
<b>Initiative, Formulating the problem description</b>	No problem formulation	Only with help of supervisor	Takes initiative, but relies heavily on supervisor	<b>Needs little help for further elaboration</b>	Needs no help for further elaboration	A
<b>Seeking expert advice</b>	Does not realize when external expertise is needed	<b>Waits for expertise to be offered (no active seeking for expertise)</b>	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-
<b>Communication skills (written only)</b>	explanations are not understood mostly	explanations can be understood with some effort and questioning	<b>understandable, to the point, can be one-way</b>	understandable, to the point and can be convincing	understandable, to the point, can be convincing, involves others in communication	B
<b>Technical skills</b>	needed explanations for execution of the tasks	demonstrated skills while help was needed for execution	<b>could work independently</b>	contributes as an equal teammember	brings new solutions and develops competences	B
<b>Teamwork</b>	Does not demonstrate ability to work in a team nor make a team	Works well together with other people	<b>Involves, if triggered by supervisors, the right people in the project</b>	Involves the right people in the project	Teampayer, 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 envelope have been properly applied.

Table 3. Score list of the teachers following the rubrics

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	10	8	8	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 2<sup>nd</sup> assignment is executed in teams. The table contains all scores of the teachers for each student, for the 2<sup>nd</sup> assignment. Behind this is the column with the individual scores for the 1<sup>st</sup> assignment which weighs for 40%. Next, the total scores for the 2<sup>nd</sup> assignment are given, weighing for 60% of the total score. The last column gives the total score. One team member dropped out for the 2<sup>nd</sup> assignment and left the course. In Fig. 4 we present the scores by company vs teacher using rubrics in Table 1 and 2 respectively.

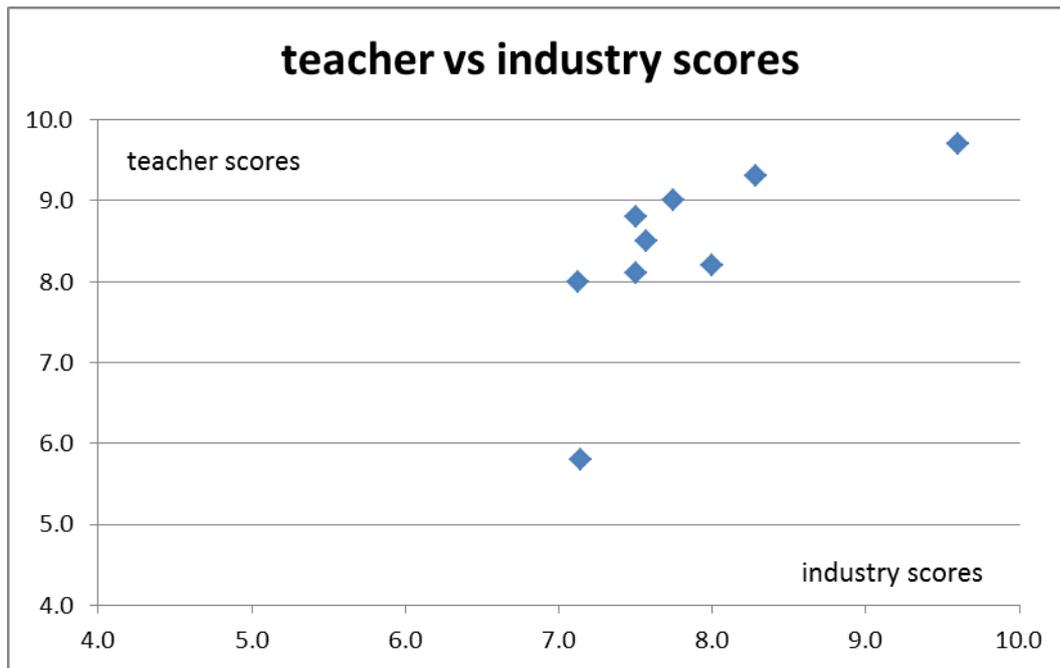


Fig. 4 Scores by company vs teacher using rubrics in Table 1 and 2 respectively

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.

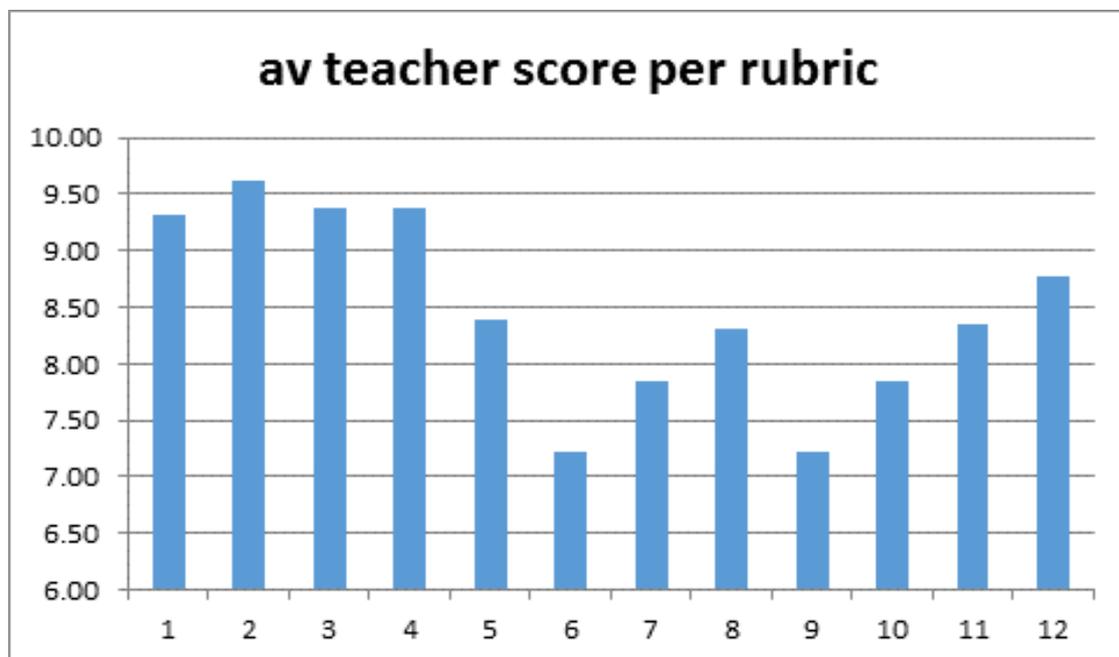


Fig. 5 Average cores by the teachers per rubric

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).

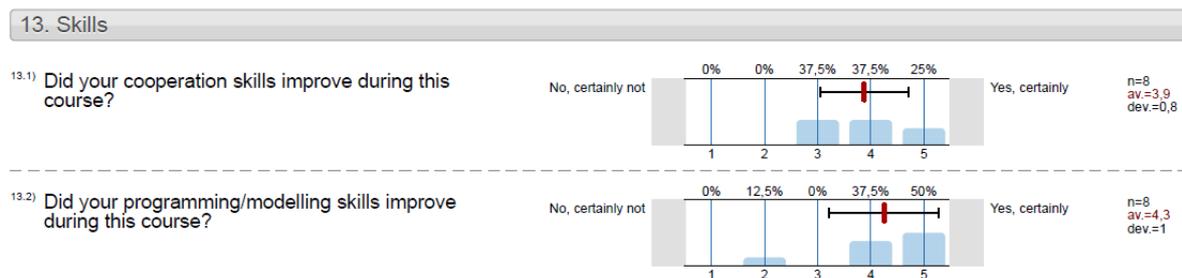


Fig. 6 Students' perceptions regarding cooperation skills and modelling

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 extent 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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