The Energy Storage and Transport (EST2020) project

Main findings of Mechanical Engineering's 1st full-scale challenge-based learning project

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Introduction

This report discusses the main findings following from the education innovation fund project *"Mechanical Engineering's 1st full-scale challenge-based learning (CBL) project"*. The objective of this education innovation fund project was to implement the full-scale CBL modeling case "Modeling of time-dependent systems: Energy storage and transport (EST2020)". This implementation encompasses the redesign of the technical challenge (project description, syllabus, rubrics, *etc.*), the reconsideration of the role(s) of the teachers and the tutors (tutor trainings, feedback instruments, *etc.*), and the redesign of the assessment procedure.

The EST2020 education innovation project on the one hand resulted in the implementation of the first full-scale CBL-project at Mechanical Engineering. On the other hand, the project aimed to contribute to the knowledge about the development of CBL at TU/e. In particular, the large-scale application of the CBL-concept has provided insights that go beyond CBL-experiments conducted on smaller scales. The goal of this report is to disseminate the most important findings of the EST2020 innovation fund project.

<table>
<tr><th colspan="2">The Energy Storage & Transport (EST2020) project - EST2020.github.io</th></tr>
<tr><td>The EST2020 project...
...is a 2nd year elective Bachelor college course offered by the department of Mechanical Engineering.
...in 2020-2021 was taken by 159 students, divided over 34 groups of ~5 students.
...involved 2 lecturers,
2 experienced teaching assistants (TAs) and 9 student tutors.
...received ~1500 views on its YouTube playlist.</td><td>Course description:
Understanding the time-dependent behavior of a system is of the essence in many engineering applications. To analyze the time-dependent behavior of systems, use is made of models. To provide a setting for getting acquainted with the full cycle of model development, this challenge-based project is placed in the societal context of the energy transition. Within the framework of challenge-based learning, the project groups independently define their own energy storage and transport solution. The goal of this project is to develop a mathematical-physical model for an energy storage and transport system, and to validate this model using experiments.</td></tr>
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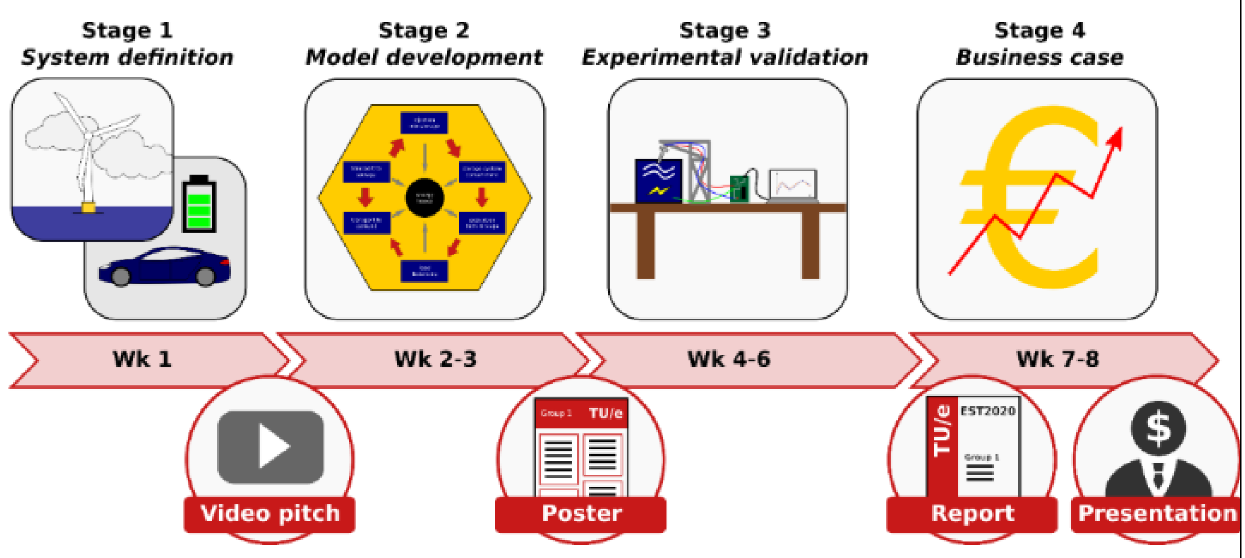
Graphical overview of EST2020



Project findings

This report categorizes the main findings of the project as follows:

1. Setting the problem space
2. Supervision and feedback
3. Organization and communication

Each of these categories is discussed in detail below. Examples from the project are included to illustrate the findings.

1. Setting the problem space

Choices and reasoning

- Student groups have one week to define their own challenge. To ensure that all learning outcomes of the course will be met, the defined challenge must meet certain predefined (technical) requirements.
- Student groups are assessed based on learning outcomes which can be met regardless of whether their final product is a success. Students are encouraged to work within their zone of proximal development (even when they do not fully see the end point yet) and to critically review their (intermediate) results instead of 'sell' their final product.

What works

- Satisfactory spread of challenges regardless of the imposed (technical) requirements.
- Having groups pitch their chosen challenge at the end of the first week forces students to start quickly. Slow starting groups are immediately corrected with a "No go" decision and a mandatory resubmission two days later.
- Time constraint in choosing a challenge avoids groups converging towards the same 'safe' challenge.

Challenging from student perspective

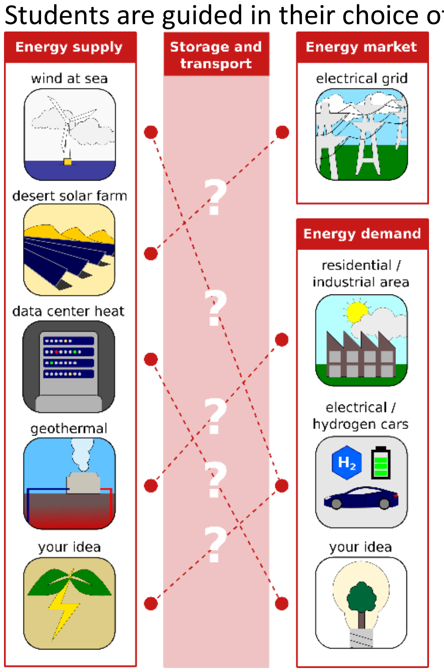
- Strict timeline does not allow for delays (in making decisions).
- Because of the imposed (technical) requirements on the challenge, the challenge cannot be defined without thinking ahead.

Challenging for teaching staff

- The spread in challenges means that as teaching staff, you have to be confident and competent in coaching students on the learning outcomes without knowing all the details of their project or the exact answer. This requires mastery of the material at a level which cannot be expected from regular teacher assistants.
- Students need to be given the trust and encouragement to work within their zone of proximal development, and the reassurance that choosing a more 'risky' challenge will not negatively impact their grade. This trust and reassurance can only be provided via direct contact with someone with the proper mandate (meaning, a member of the teaching staff, and not a teacher assistant).

Examples from EST2020

- Students are guided in their choice of challenge by examples of energy supplies and demands:



- At the end of the first week, the groups presented their ideas through a video pitch. The selection of the challenges included:
    - Hydroelectric dams
    - Thermo-chemical energy storage
    - Gravitational energy storage
    - Flywheel storage
    - Magnetic marble track storage

2. Supervision and feedback

Choices and reasoning

- To guide the students in terms of technical content, the teaching staff interacts with the student groups on a weekly basis.
- To create a clear distinction between the interactions with the teaching staff and the interactions with the tutors, the weekly tutor-supervised meeting focuses on organizational matters (planning, evaluation, personal learning goals, *etc.*) instead of on technical content.
- To ensure that students can learn during the timeframe of the course, the assessment components are spread out over the course. They receive rapid (within a few days) and detailed (written, followed by an oral clarification by the grader) feedback on all deliverables.
- Groups continuously review their performance as a group and the performance of individual group members by together filling in an evaluation form, under guidance of the tutor.

What works

- Interacting with the students on a weekly basis allowed for coaching tailored to the specific groups.
- The spread-out assessment components ensured that students remained on track, were given sufficient feedback, and could improve within the time frame of the course.
- Giving feedback within 1 or 2 days optimized learning within the short time frame of the course. Waiting longer would have been detrimental to the progress of the students.
- Providing oral elaboration on the written feedback was often experienced to be clarifying and enabled the teaching staff and students to align their expectations.

Challenging from student perspective

- Students had to get accustomed to the idea that the teaching staff was directly available for advice/discussion (technical, clarification of assessment criteria). Students had to transition from only giving answers they feel confident about to openly discussing their thought process along the way.
- Student tutors are generally found to be ill-equipped to provide the coaching required for a CBL project, also when their coaching is reduced to organizational matters (planning, evaluation, personal learning goals, *etc.*). As a result, student progress in these areas is lacking and tutor meetings are not experienced to be beneficial.

Challenging for teaching staff

- It is not possible for the teaching staff to directly control the coaching done by the tutors during the tutor meetings. Better control on this could help to improve the course experience of the students.
- The rapid assessment of deliverables and the availability for scheduled live interaction has a pronounced impact on the schedule and time-management of the teaching staff.

Examples from EST2020

- The 34 groups are divided into 4 subgroups of ~40 students/8-9 groups. Every subgroup spends one half day (4 lecture hours) per week in Innovation Space supported by a lecturer and an experienced TA. During these hours, students work together in their groups, use the provided facilities to build an experimental set-up, discuss their work with the teaching staff, and receive feedback based on their submitted deliverables.

- Approximately 30% of the groups received a "No go" decision on their pitch, mostly because they did not take it serious enough. Most of these groups changed their approach to the project based on the "No go" decision and were able to have a successful project following a resubmitted pitch.
- A constructive alignment table showing the alignment between the learning outcomes and the assessments is used to guarantee that all (technical) learning outcomes are covered (with the appropriate weight). The assessment criteria (rubric items) of the deliverables are directly linked to this table.
- Assessment criteria for all deliverables are available at the start of the course. Each criterion has a header (shortened version of the corresponding learning outcome) and a short description of what is required. For example, one of the criteria for the poster is:

> * Mathematical-physical model *
> A crucial, time-dependent, component of the system is described by a differential equation.

- When assessing the deliverable, the grader uses a more extensive feedback table (which is not communicated to the students), from which feedback is directly copied for the students. This way, elaborate feedback can be provided in a short time frame and uniformity of assessment between the groups is guaranteed. For example:

Mathematical-physical model (1 point per sub-criterion)		
A crucial, time-dependent, component of the system is described by a differential equation.		
Time-dependent component	(-) A crucial time-dependent component of the system is not identified, and/or it is unclear why the identified component is important.	(+) A crucial time-dependent component of the system is identified.
Quantity to be predicted is clear	(-) The time-dependent quantity/quantities to be modeled are not clearly specified.	(+) The time-dependent quantity/quantities to be modeled are clearly specified.
Model physics and structure	(-) The structure of the proposed model for the crucial component is unclear and/or does not make sense.	(+) The structure of the proposed model for the crucial component makes sense.
The differential equation	(-) A differential equation (or equivalent model) is not proposed, and/or the proposed model does not make sense.	(+) A sensible differential equation (or equivalent model) is proposed.
IVP/BVP definition	(-) The initial/boundary value problem is not clearly and precisely defined.	(+) The initial/boundary value problem is clearly and precisely defined.

3. Organization and communication

Choices and reasoning

- Making a course/project Challenge-Based should not mean that the assignment becomes incomplete and unclear. Making an assignment open-ended is not the same as making it a guessing game where students should try to figure out which one 'right' answer the teacher wants to see. On the contrary, because the assignment is more open-ended, focus should lie on communicating clearly to students what requirements their work should meet. In response, the teaching staff should be open to a wide range of challenges and solutions within the scope of the requirements.
- To provide a clear overview of the course and to avoid duplicating information throughout various documents, all information is provided in one clear page (EST2020.github.io). The page is easily accessible via the Canvas home page of the course and includes direct links to informative animation videos and to the Canvas assignments corresponding to the various deliverables.
- All deliverables have a corresponding Canvas assignment in which any group member can submit work on behalf of their entire group. Written feedback on the deliverables is posted via the SpeedGrader and readily available for all members corresponding to the group. Grades for group work are automatically assigned to all group members and visible to students via the Grades tab.
- The teaching staff is in regular contact with the student groups during scheduled hours and via the public discussion board on the Canvas page of the course. It is made clear to students that any other form of communication (e.g. e-mail or Teams chat) will only be responded to in case of exceptional (personal) circumstances.

What works

- Clear communication of course information and assessment criteria (directly linked to the learning outcomes) avoids guesswork from the students and ensures coverage of all learning outcomes.
- Strict schedule keeps students on track and ensures that derailing groups can be caught and coached in a timely manner.
- Proper use of Canvas functionalities provides clarity to both students and the teaching staff and reduces time in processing deliverables.
- Limiting communication to scheduled hours and the Canvas discussion board makes increasing student numbers more manageable.

Challenging from student perspective

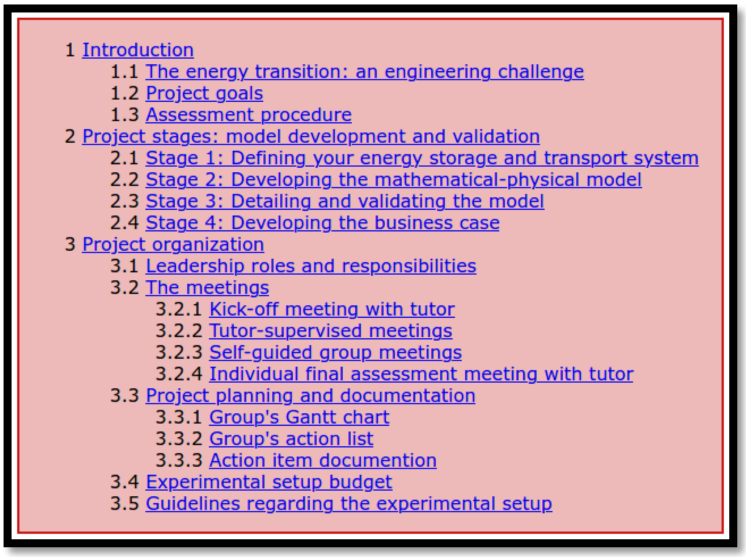
- In the initial stages of the project, students make (incorrect) assumptions about what is required of them (in terms of deliverables) instead of carefully studying the published assessment criteria and asking the teaching staff for clarification. This is not because they do not appreciate the clarity, but because they are not used to it.
- Students struggle with developing a feeling of what level of performance (where the bar lies) and time investment is required from them. The impression is that students feel that for a project-based course (the DBL setting), the level and required time investment should be significantly lower than for a regular course. This is also reflected in the feedback given by students.

Challenging for teaching staff

- Finding the right balance between setting clear expectations and encouraging students to think critically for themselves when it comes to openness about assessment criteria beforehand.
- Deciding on what information to include in the public rubric, and what in the underlying teachers-only scoring sheet.

Example from EST2020

- All course information is placed on one comprehensive page with a clear outline:



1 Introduction
    1.1 The energy transition: an engineering challenge
    1.2 Project goals
    1.3 Assessment procedure
2 Project stages: model development and validation
    2.1 Stage 1: Defining your energy storage and transport system
    2.2 Stage 2: Developing the mathematical-physical model
    2.3 Stage 3: Detailing and validating the model
    2.4 Stage 4: Developing the business case
3 Project organization
    3.1 Leadership roles and responsibilities
    3.2 The meetings
        3.2.1 Kick-off meeting with tutor
        3.2.2 Tutor-supervised meetings
        3.2.3 Self-guided group meetings
        3.2.4 Individual final assessment meeting with tutor
    3.3 Project planning and documentation
        3.3.1 Group's Gantt chart
        3.3.2 Group's action list
        3.3.3 Action item documentation
    3.4 Experimental setup budget
    3.5 Guidelines regarding the experimental setup

- Extensive use is made of infographics and supporting videos to guide the students through the project.

Concluding remarks and recommendations

This project has provided insights into the large-scale application of the CBL-concept. By properly (re)designing the EST2020 project – in particular the project setting, the assessment procedure, and the teacher-student interaction moments – the students found a good balance between enjoying the open-endedness of the project and achieving the expected technical quality. It was observed that regarding some fundamental aspects (especially mathematical-physical modeling) the students lacked the proper knowledge. The (CBL) project setting does not provide the room to train students on such fundamental aspects as part of the project. Fundamental knowledge should, in our opinion, not be transferred as part of a project, but it would be good to create/reinforce clear connections between fundamental courses and projects such as EST2020. With respect to professional skills the students were often unable to set the bar right. To some extent this can be repaired within the project by proper expectation management (for example, offering students a “good example” of previous years), but better alignment between the skills trainings and the projects would also be beneficial.

In terms of the scalability of the CBL concept as applied in EST2020, the primary concern pertains to the workload for the teachers. We believe that direct involvement of experienced coaches is an essential ingredient of the explored concept. Although this is a very enjoyable and rewarding task for the teachers, coaching is very time consuming. The current generation of tutors was not experienced to be well-equipped to substantially aid in the CBL coaching. Although this can be improved by more CBL-oriented tutor trainings with tutors that experienced CBL teaching themselves, the coaching demands for the CBL setting in EST2020 can in our opinion not be completely transferred to the tutors without compromising the quality of the course. Tutors should, however, be a part of the solution for making a CBL project such as EST2020 scalable. This should be done by creating a clear division of tasks between the tutors and the teachers, where the efforts of the teachers should be focused on the high-level coaching aspects. Here we also see an opportunity to integrate general student coaching activities in CBL courses such as EST2020. Providing a development track for students who have affinity with coaching to become experienced CBL tutors could also alleviate the workload for the teachers.