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Teaching a hands-on course during corona lockdown: from problems to opportunities

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Abstract

Teaching a hands- and minds-on course, in which feedback is essential in order to learn, is difficult, especially in times of COVID-19 where student progression cannot be monitored directly. During the lockdown period, the workshops of an undergraduate Design Engineering course had to be transferred to the home situation, which required a redesign of this course by the staff. It also provided new opportunities for students to adapt to this situation, which required extra creativity and problem-solving skills. The adapted workshops revealed conditions that enhance maker education. However, providing timely feedback required a substantial amount of time not anticipated for. We also report that short instruction videos seem to work much better than longer lectures or tedious materials. As we practice what we preach, we will evaluate the course and apply our design knowledge acquired over the years.

Keywords: design engineering, COVID-19, practical work

Supplementary material for this article is available online

1. Introduction

Design Engineering for Physics Students (DEPS) is a six ECT hands- and minds-on freshman course in the 2nd semester of the undergraduate program of Applied Physics at Delft University of Technology. The approximately 150 students learn to apply abstract physical concepts in designing solutions to problems they will encounter in their career, such as calibration of sensors or isolating a sensitive device from environmental vibrations. The associated topics are covered in a theoretical sense in preceding courses, but are applied hands-on during the workshops and final assignment of DEPS.

We were only halfway through these workshops when the COVID-19 measures forced us to redesign the course. In this paper we elaborate on the challenges we faced in redesigning the course under large time pressure. It forced us to quickly adapt to the new situation, propose an initial solution, and adapt subsequent workshops based on quickly gathered student feedback and teaching staff feedback. We will use one workshop as an example, yet report on the finding from all three workshops. Templates of notebooks used in these three workshops are provided for fellow teachers to use in their own courses. Since the final assignment is still running at the time of initial submission of this manuscript, we only briefly elaborate on the changes to the final assignment, but cannot reflect on them yet. However, at time of publication the final assignment had taken place, see Hut (2020a) for a video impression. We review our decisions, mistakes, provide solutions to various challenges and present feedback from both teachers and students to our solutions.

2. Course design

DEPS was designed as a 'maker education' course in which students learn through designing and building the actual physical devices that are their solutions. Maker education builds on the works and philosophies of constructivists like Papert and Piaget Libow Matinez and Stage (2019, Van Dijk *et al* 2020). Radical interpretations of maker education boast a 'give them a playground and they will learn' attitude. Rather than only playing around, we strongly believe in the added value of the teacher and made sure the course is 'guided education' Kirschner *et al* (2006). Students have freedom to decide their own designs and solutions, yet the assignments are structured in such a way that the students have to incorporate/apply the learning goals to succeed at the assignment. See the examples presented later on, or Hut (2018) for more on the philosophy of this style of teaching.

The course aims at attaining the following learning goals:

1. Designing, realizing and testing of a physical apparatus or a physical measuring or manufacturing process
2. Gaining knowledge of the different design methods and being able to apply these depending on the problem/assignment
3. Elementary knowledge on manufacturing techniques
4. Knowledge on sensors and data processing
5. Cooperation and working in groups
6. Dealing with practical boundary conditions
7. Reporting and presenting a design
8. Using simulation packages

To attain these goals, students are offered six full-day design activities, consisting of lectures at the start of the day, followed by workshops in which they have to:

1. Design, build and use a test-setup to calibrate a sensor of their choice.
2. Design and build a sensor based on changes in capacitance.
3. Design a field effect transistor (FET) for use as an analog amplifier or a digital invertor. (Students design the both the abstract circuitry and the semiconductor layout on a wafer. We actually have these transistors fabricated and, once back from production, students have to measure if their design works.)
4. Design and test an echo acoustic algorithm than can locate an object on a table.
5. Design, build and test a setup that can isolate a sensitive device from environmental vibrations.
6. Design, build and use a microscope capable of reading the print on your own FET from assignment 3.

Each time, the required design steps are different and strictly specified. Students address these requirements accordingly. This forces the students to work with different design approaches, from monolithic design (workshop 3 above) to fast iterative prototyping (workshop 4). Passing the assignment is done when students demonstrate a working device at the end of the day. To help students in designing a feasible solution, a series of lectures is offered on uncertainty analyses and error propagation, 'guesstimation' of variables, material selection and proto-type boards. Topics covered in these lectures are tested using a written exam on a case.

All knowledge gained accumulates in a final assignment where student demonstrate their knowledge and skills by designing and building a demonstration setup that is usable by their former high school physics teacher. This is 'tested' by organizing a science fair at the end of the course where students present their demonstrations to both the teachers of DEPS as well as their former high school teachers (who are invited to this event).

All workshops and the final assignments are done in 40 to 60 groups of three students and take place in one massive, well equipped (studio) classroom (SCR), giving student access to tools and materials needed for their builds. The teachers of DEPS are supported by a team of nine Teaching Assistants (TAs) on days of teaching activities, an additional three 'chief-TAs' who also help out in between teaching activities with logistics and with grading of student work and the SCR's supervisor, who assists with providing materials and other logistics within the SCR. Finally, all practical courses of the department, of which DEPS is one, are supported by three administrative colleagues.

2.1. Minimise vibrations: an example of a typical on-campus workshop

In the following, one specific workshop will be considered in more detail in the context of the redesign process in the on-campus situation. The workshop, see figure 1, focuses on attaining learning goals 1, 2, 4–7 by reducing vibrations.

Isolating sensitive (measurement) devices from environmental vibrations is a challenge that many physics graduates will encounter in their career. In this workshop students are tasked to design, build and test a setup that can reduce the amplitude of a 5 Hz vibration by at least a factor of two. The task is a typical example of parametric design in which students first analyse the physics of the problem and reduce the assignment criteria to a parameter range: if the parameters of their design fall within the range, they are certain that the design satisfies the assignment.

In non-COVID-19 times the workshops started with a 45 min lecture given by Professor Dr Ir Kruit to elaborate on the importance of isolating measurement setups in his particle optics lab. The lecture includes a demonstration in which it is shown that even seemingly non-moving objects in the lecture hall are vibrating. He subsequently explains the main idea of reducing vibrations by using mass spring systems. The focus is on the parameters that students can influence during the assignment: mass and spring constant. Subsequently, the main assignment is elaborated, specifying available tools (assorted materials like rubber bands, sponges, wood, duct tape, etc to build their setup) and materials (a vibration platform and two accelerometers that connect to Arduino's) and the rules/requirements for the day by the head teacher of DEPS.

The students are provided with a template file (Jupyter notebook) that guides them through the steps of the design cycle. In this template they also have to report on their progress and results. A version of this notebook translated into English is provided in the supporting materials. The steps the students go through the rest of the day are:

- Check if accelerometers work properly
- Calculate allowed parameter range
- Determine parameters of given materials (mass, spring constant)
- Design a setup that falls within the allowed parameter range
- Build, test and (if needed) iterate.

At the end of the day their setups are assessed using the prescribed criteria and students hand in their logbooks (i.e. templates).

3. Impact of the lockdown

The corona virus lockdown started after the third workshop of the DEPS course and as a result no on-site education was allowed anymore. For a hands-on course like DEPS that relies on the students working with provided tools and materials, this posed a rather big problem. As one can imagine, workshops as described above could not continue. It is clear that the staff faced many challenges in redesigning these workshops for 150 students who were located all over the Netherlands.

Our intent was to still acquire all of the aforementioned learning goals. We thereby re-evaluate which parts of the assignment were really helping the students to attain these, which parts of the workshop could be still carried out in adapted form, and what other assignments could be devised to attain the goals. This approach is in line with the way we teach our students how

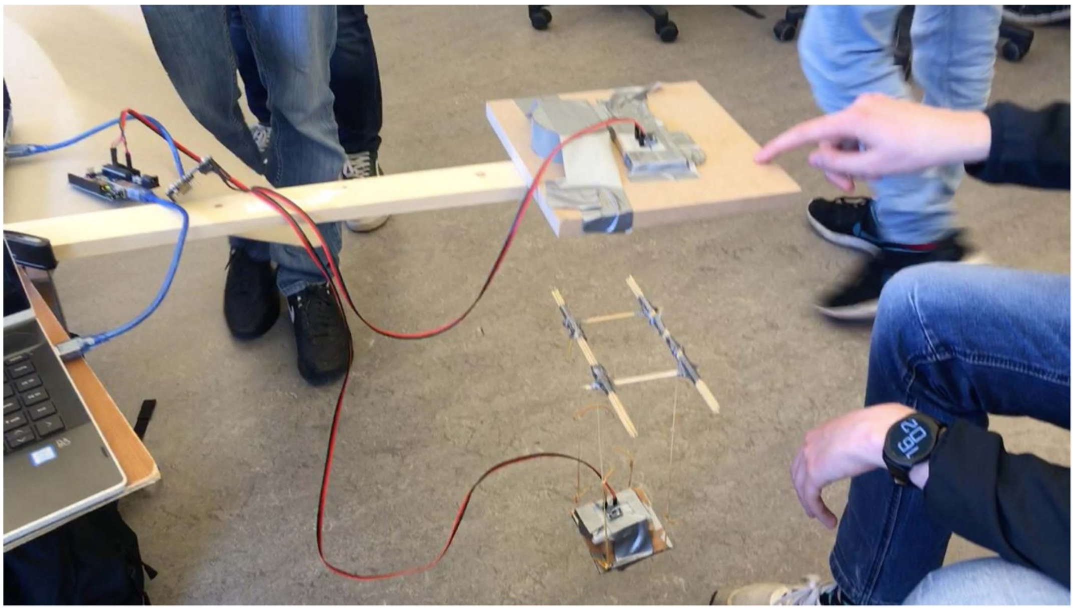

Figure 1. Example of a setup made by students for the on-site (original, pre-lockdown) version of the 'minimise vibrations' workshop. The vibration platform (upper wooden platform attached to the desk by a springy wooden stick), the two accelerometers and building materials are provided by the teaching staff. The Arduino's used to readout the accelerometers are provided at the start of the course and used in multiple workshops. This is a screenshot from a short movie that is provided as supporting material to this publication (available online at (stacks.iop.org/PED/55/065022/mmedia)).

to design: formulate criteria, investigate various options, choose one, apply, test and evaluate. Based on this re-evaluation, we decided on the following core design rules for changing the remaining three workshops[1]:

– Students should be able to complete each assignment in the original 8 h, but are given more time to hand in their results. This allows students to be flexible in how and when they do the assignment in their lockdown home situation. They are expected to work on the assignment during the scheduled hours. At those times online teacher and TA support is available.
– Instructions should be kept to a minimum and should be as clear as possible, since communication back and forth requires more time than usual.
– Checks are built into the structure of the assignment to make sure students are on the right track and on the right time schedule to finish the assignment on time.
– Students have to be able to complete the assignment using materials found at home.

Since clear communication is essential for students to do what is required, we decided to:

- Use pre-recorded videos teacher's instructions shared in a YouTube playlist Hut (2020b).
- Use Discord for two-way communication (i.e. student-student, student-teacher interaction). The online platform often used for communication between gamers was found best suited to quickly and interactively communicate between various persons.

[1] Writing this down after the fact, this process sounds more deliberate than it was during the actual redesign of the course. We would like to stress the importance of having a team of both early career 'can do'-enthusiasm and more senior 'seen it before, this does/does not work'-experience in the teaching team.

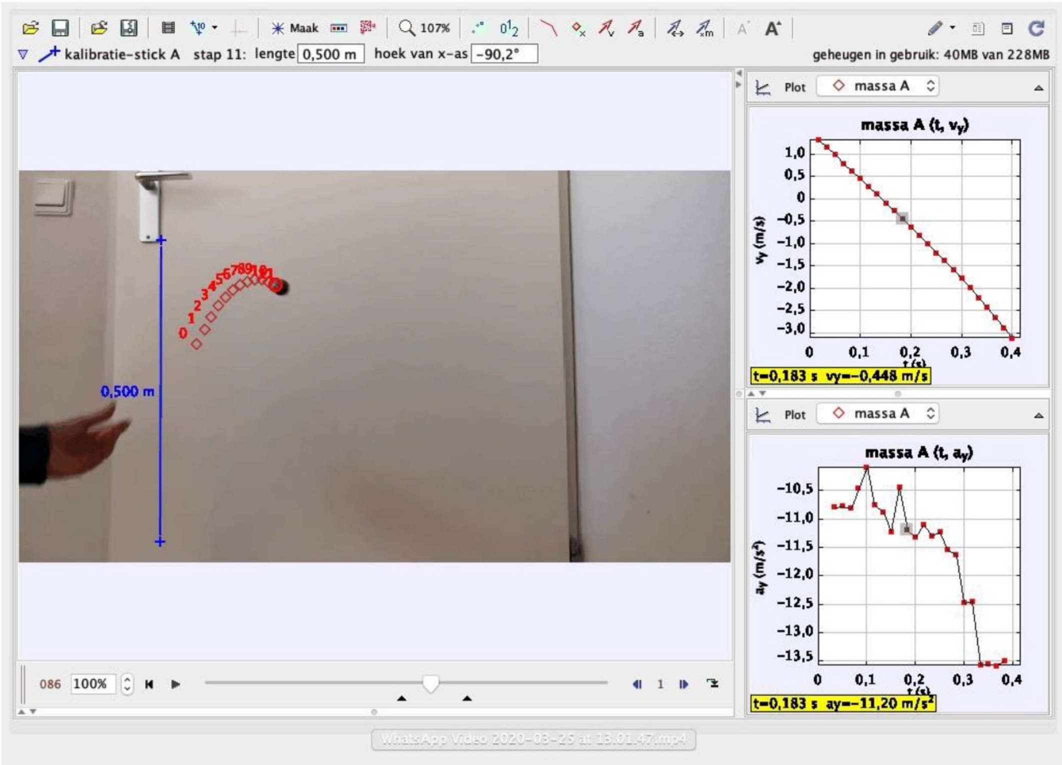

Figure 2. Screenshot of the Tracker software during the 'sanity check' where students have to record themselves throwing a ball, track its position and derive the horizontal velocity of the ball over time. Sanity checks gave teachers and TAs the opportunity to quickly assess if students can use the technology used during the assignment. The full (moving) gif file the student uploaded is provided as supporting material.

Based on the design rules for the workshop, its structure changed as well. At the start of the day students are provided with a Jupyter notebook template (Python) that both guides them through the workshop day and that has entries they have to fill in themselves. These are similar to the templates that would have been used under normal circumstances, but are made more detailed since asking questions takes longer during lockdown (see communication above). We devised 'sanity check' assignment on Brightspace (our online educational environment) that were handed in during the day. These sanity checks were checkpoints that ought to make sure that students are engaging with the assignment and are 'on schedule'. These checks range from showing that a particular piece of software is working, to delivering a first-idea sketch. Sanity check assignments ought to make sure that students are engaging with the assignment and are 'on schedule'. When handed in, teachers and TA's quickly analyse these assignments to see if students are on the right track and approach (through Discord) those that are not. This replaces the 'walking around in the room' that a teacher normally does to spot students that are struggling.

At the end of the assignment the students hand in (a pdf of) their notebooks for grading by TA's and teachers. Where normally the students have to show a working device at the end of the day, they are now given a larger time window to upload a PDF of their template that shows their device works. This extra time is given to allow students to be flexible with their time in these unusual circumstances.

3.1. Minimise vibrations: an example of a typical workshop at home

The prefab setup with accelerometer and the vibration platforms, normally provided by the staff, are not available at home. Therefore, we

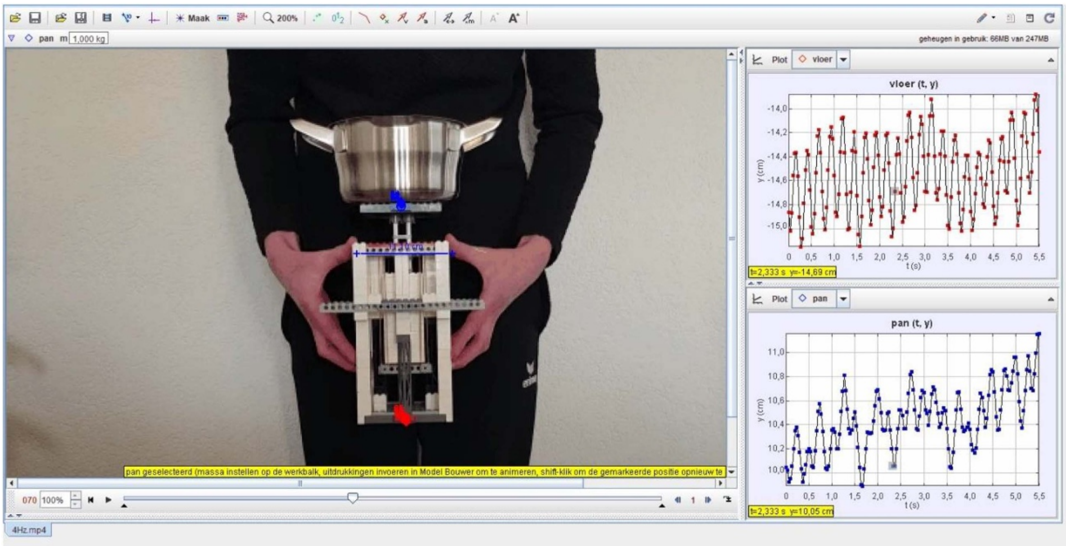

Figure 3. Screenshot of the Tracker software with final result. This student used LEGOs and rubber bands to isolate the measurement device (the pan, blue dots) from the vibrating floor (Dutch: 'vloer', red dots). As can be seen from the graphs tracker provides (as well as from the full moving gif file, provided as supporting material) the student succeeded in building a setup that can suppress vibrations.

encouraged students to look for 'anything that absorbs vibration' at home. The vibrating platform was replaced by their own hands. To analyse the reduction in amplitude, students filmed themselves while shaking their setup. They subsequently analysed the recorded movie using the (free, open source) 'Tracker' software (Tracker, version 5.1.3, Open source Physics 2019).

At the start of the workshop day, five videos were released on Youtube:

- Explanation of how the assignment fits in the rest of the course and introduction of parametric design (4 min).
- Explanation of the larger context of the assignment: examples of why it is important to be able to isolate devices from environmental vibrations (including using the LIGO gravity waves (Caltech 2017) experiments as examples) (10 min).
- Derivation of the relevant equations for the assignment, starting from first principles (30 min).
- Explanation of the assignment and how it would be graded. This includes everything that is expected from the students during the assignment (12 min).
- Explanation how students can record their setup properly and how to analyse their recorded video in 'Tracker' (30 min).

After watching these videos, students have to do a sanity check: record themselves while throwing a ball straight up and analyse the trajectory of that ball using 'Tracker' and upload the result. We had to judge whether the students were capable of recording video at the required quality and could use the 'Tracker' software and if they were capable of recording video at the required quality for the assignment. After this sanity check students followed the same steps as in the original workshop, but now using things found at home:

- Calculate the allowed parameter range.
- Determine parameters of materials available at home (mass, spring constant).
- Design a setup that falls within the allowed parameter range.
- Build, test and (if needed) iterate.

Figures 2 and 3 show screenshots from Tracker from the students. Both a screenshot from the sanity check (throwing and tracking a ball) as well as the final result are shown. During the

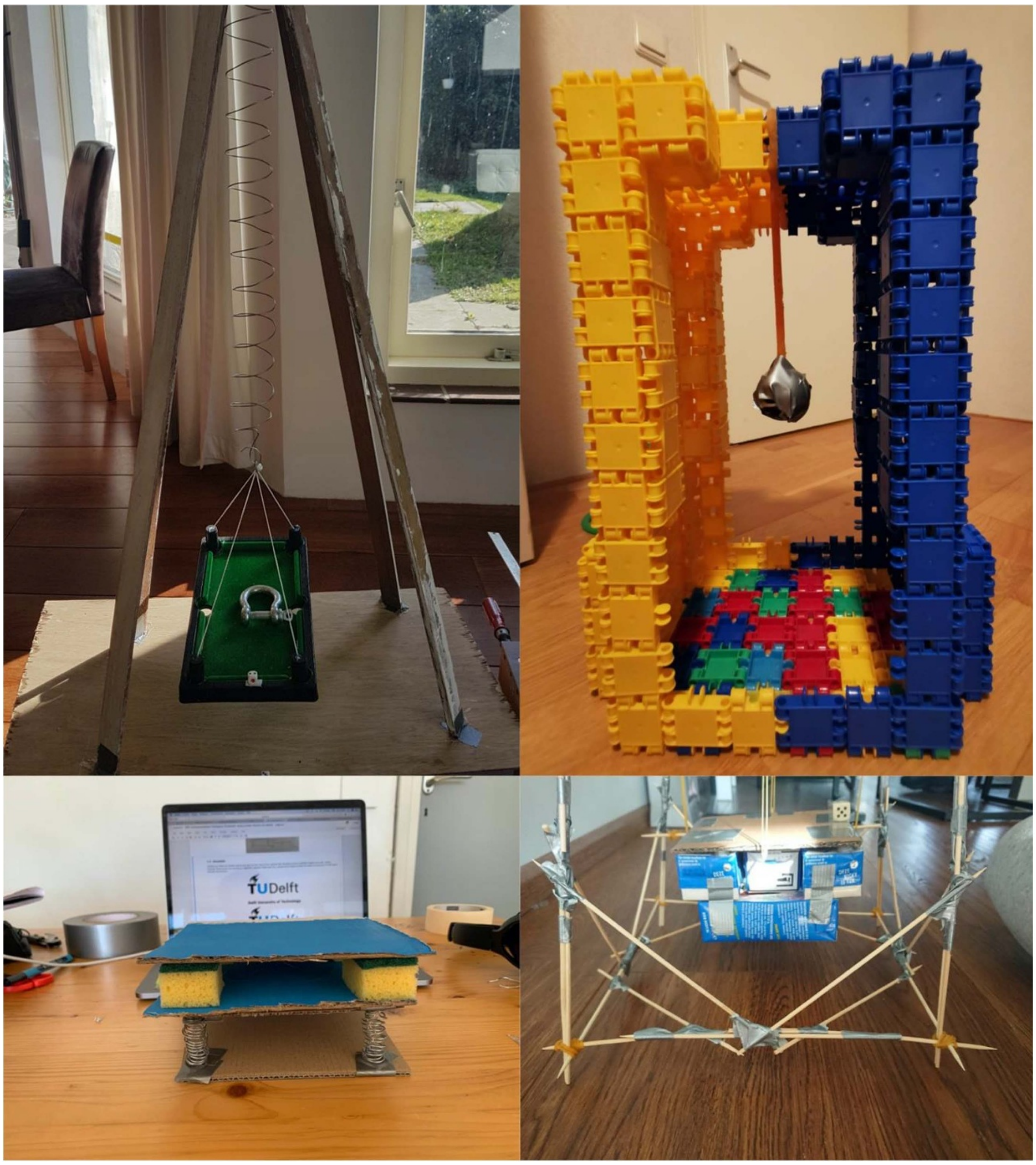

Figure 4. Collage of set-ups built and photographed by students.

workshop day a team of TA's was available online on Discord to answer questions.

After the workshop, TA's and teachers quickly graded all notebooks. This was binary grading: either 'OK' or 'please amend these points'. Finally the principal teacher recorded a video with feedback to the students: praising students for their efforts, showing some of the designs made to the entire group, urging students who had not submitted yet to do so and looking forward to the next workshop. This video was made to add a touch of 'human interaction' in these times of working remotely.

4. Evaluation of the workshop

We were positively surprised by the quality of the submitted work. Students managed to use things found at home, from old panties to LEGO's, to build their setup. Figure 4 shows a collage of setups built by students. Informal student feedback indicates that the strict structure of the workshop with respect to steps to be followed was appreciated. It is our hypothesis that *for successful maker education one has to offer strict guidance on either the topic, or on the structure of the assignment*, but not on both or neither. Given the limited resources found at home, one has to offer freedom on the topic, so a stricter structure is needed to guide the students. Students also mentioned that providing explanation in separate videos allowed them to look up a relevant parts when stuck during the workshop. Although these videos were not shared outside of the student population, the view numbers were much higher than student numbers, indicating multiple viewings. Finally, some students mentioned that the final feedback videos, even though they did not include any essential information for the assignment, did help them to feel connected to their fellow students and teachers while working remotely.

Given that students did not work in groups on this assignment, the grading load was triple that of a normal workshop. This proved a problem for TA's and teachers, working all weekend to provide timely feedback to the students. Partially because of this it was decided to have the students work online together in the final assignment of the course. In this final workshop students had to, as a team, decide on a set of criteria that their design had to achieve. They subsequently individually all designed and built a solution, and finally came (online) together to judge which of their three designs met their (self-set) criteria best. They submitted this design for grading. This did ease the grading load in that final assignment.

Finally, some students had trouble with the extended deadline: by providing more time, they intuitively assumed more time had to be spend on the assignment and put in more hours than planned by the teachers, at cost of their other courses (and their sleep).

5. Concluding remarks

In this paper it is described how a typical hands-on undergraduate course has been transformed into a home-based course. Templates used in this course as well as the study manual are provided to fellow teachers as supporting material to this publication. Learnings from this experience are the fact that short instruction video's work much better than longer lectures or tedious manuals, students took the course seriously and often came with creative solutions for their home assignments, more freedom for the home assignments means that more stricter guidance of the process is required and that the (online) grading is very labour intensive and needs to be simplified as much as possible.

Acknowledgments

The authors thank all supportive staff, including teaching assistants, for their help in making this course available in these difficult times.

Ethical statement

This observational study of the Design Engineering for Physics Students (DEPS) course given at Delft University of Technology during the COVID-19 lockdown respected the privacy and psychological wellbeing of the individuals observed and posed minimal risk to the students. No personal data was collected and the work cannot lead to identification of the individuals that took part in the course. Students gave permission for the photographs to be published.

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