Lessons Learned 1, 1&2 (2021)
Submitted: 31.05.2021
Accepted: 21.06.2021
DOI: https://doi.org/10.25369/ll.v1i1/2.29
ISSN: 2749-1293 (Print); 2749-1307 (Online)

Teaching at schools and universities in times of a pandemic - A field report from the perspective of physics didactics

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Abstract

Die Einschränkungen in der Präsenzlehre sind insbesondere für experimentelle Wissenschaften wie die Physik eine besondere Herausforderung. In diesem Beitrag wollen wir einige Hilfsmittel und Konzepte vorstellen, die sich in der Ausbildung von angehenden Physiklehrer*innen bewährt haben. Wir werden getrennt auf die verschiedenen Veranstaltungsformen (Vorlesungen, Seminare, Praktika) eingehen und diskutieren, wie sie in einem Online-Format umgesetzt werden können. Tools wie Zoom, Ilias, Mural etc. können dabei insbesondere kooperative Lernformen unterstützen, die in der Online-Lehre besonders nützlich sind, um ein Mindestmaß an sozialer Interaktion zu gewährleisten. Außerdem stellen wir Konzepte vor, die zu einer reflektierteren Auseinandersetzung mit den Inhalten der Veranstaltung führen. Schließlich werden die Probleme bei Online-Prüfungen diskutiert, bei denen ein Kompromiss zwischen bestmöglicher Überwachung und der Wahrung der Privatsphäre gefunden werden muss. Hier schlagen wir mögliche Lösungen vor, die sich bereits in der Praxis bewährt haben.

The limitations of face-to-face teaching are a particular challenge for experimental sciences such as physics. In this paper, we will present some tools and methods that have proven successful in Cologne for the preparation of prospective physics teachers. We will look separately at the different types of courses (lectures, seminars, practical labs) and discuss how they can be implemented in an online format. Tools such as Zoom, Ilias, Mural etc. can support cooperative learning groups in particular, which are especially useful in online teaching to ensure social interaction. We also introduce methods that lead to students' more reflective engagement with the content of the course. Finally, we discuss the problems of online examinations, where a compromise has to be found between the best possible supervision and the preservation of privacy. Here we suggest possible solutions that have already proven themselves in our practice.

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This article was originally submitted in German.

1. Introduction

The need for online teaching poses enormous challenges for schools and universities. At the same time, it offers teachers the chance to test ideas and concepts on a large scale. This paper will discuss the opportunities but also the risks that this brings, using some examples from this large-scale experiment.

An important question is the appropriate format for the course. Lectures cannot be translated 1-to-1 into an online format. What are the possibilities here? And how can the students or pupils be engaged?

There are special challenges for the experimental sciences, especially when the pandemic conditions do not allow physical presence in laboratories. New ideas are needed here if these practical lab courses are to be interesting, instructive and safe.

Finally, there is the question of the future of teaching in the post-Corona era! Will everything be the same as before? Are there innovations that have proven their worth and will continue to enrich teaching after the current pandemic?

2. Preliminary technical remarks

The success of online teaching naturally depends to a large extent on the technical conditions. The problems associated with this (e.g. quality of the internet connection, data protection, etc.) will only be discussed here in passing.

The University of Cologne (UzK) positioned itself relatively conservatively with regard to face-to-face teaching during the Corona crisis, so that teaching would be carried out almost exclusively online since March 2020. In order to create the technical conditions for staff and students here, the UzK acquired 50000 Zoom licences. This made it possible to negotiate favourable conditions with the manufacturer, especially with regard to data protection regulations. For example, the data is only processed on servers within the EU.

Another reason for the decision to use Zoom was the members of the University of Cologne, Institute for Physics Education had previously good experiences with using Zoom over several years and under different circumstances. This meant that staff members could also be used as instructors for internal university training in the use of Zoom.

Even before the suspension of face-to-face teaching due to the pandemic, we used mobile whiteboards (approx. 80 x 60 cm plastic-coated wooden boards that can be written on with erasable markers or pens) for group work in seminars, lectures and laboratories for formative assessment. Formative assessment is the continuous examination and survey of the learner's level of knowledge in the learning process. For the instructor, it provides a way to determine the students' level of understanding of the material. At the same time, it is a tool to facilitate the assessment of your own teaching and curriculum material. Formative assessment, then, is not only about checking whether students are correct, but is also intended to explore students' underlying conceptions and competencies at the same time. A very clear introduction and discussion of the advantages and disadvantages of formative assessment can be found in [1].

With the whiteboards mentioned above, lecturers could see at a glance what understanding students had developed. After implementing online courses, we tried using the whiteboards integrated in Zoom. While the whiteboards were useful for discussion purposes, it was not easy to see all the boards at a glance and to organise and document boards. After testing several alternatives, we selected Mural [2] to replace the physical whiteboards. We found that the large lectures can be divided into Zoom Break Out Rooms (BORs) and that the lecturer can use duplicated group murals to see in real time what students are working on and what understanding they can achieve. This also allows easy sharing of work results by students in seminars, lectures and practical labs. The real-time mode allows all activities up to cursor/mouse movements of all students and teachers to be followed. However, this requires more computing power in the browser on the computer or on the tablet app for all participants. This mode can be deactivated, however.

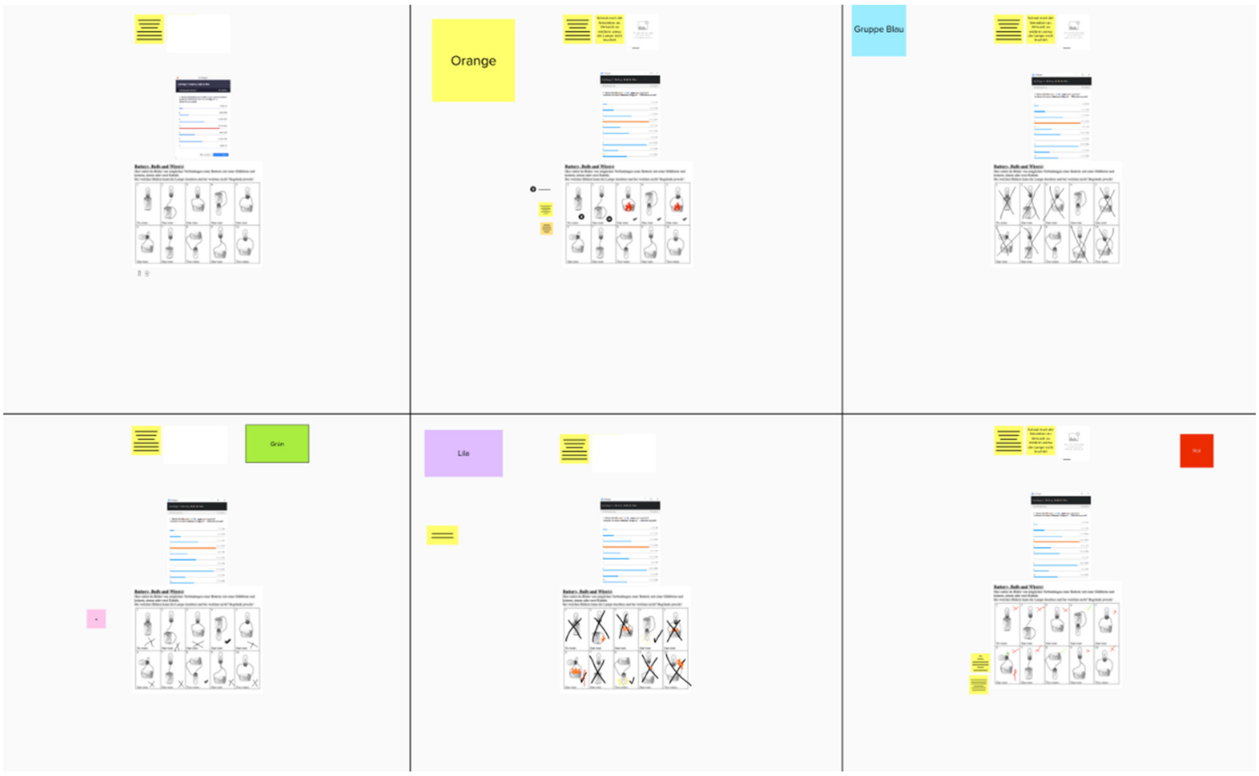

Fig. 1: Use of murals in a physics didactics (content and pedagogy) seminar: Students develop a different understanding of simple electrical circuits in groups. The figure shows the teacher's view. Each field simultaneously represents the mural of a different group (or a breakout room). The teacher therefore has an overview of the activities of all groups and can intervene if necessary. An enlarged section is shown in Fig. 2.

Another tool that has been used as standard in teaching for many years is the learning management system (LMS). Our LMS is *Ilias* (Integrated Learning, Information and Work Cooperation System) [3], with which internet-based teaching and learning materials can be created and made available. It offers a wide range of possibilities from planning events to monitoring learning progress with various test formats. The Ilias LMS also supports communication with students via email, chats or forums. The Ilias LMS was very familiar to our students, which has made the transition to online formats much easier.

3. Lectures

Lectures are the central course format at universities. There are numerous options for realising this in the context of online teaching. The simplest option, of course, is to change as little as possible. The lecture then takes place live via Zoom, with the lecturers either standing in front of a blackboard in a lecture hall or working from their home office with a PowerPoint presentation, for example. The obvious advantage is that not much has to be changed here (apart from the technical boundary conditions) compared to the classic lectures. The lack of formative assessment is major disadvantage. The communication between lecturers and students becomes even more difficult online. From the lecturers' point of view, direct feedback via facial expressions and other non-verbal interactions is missing. Therefore, it is very difficult to assess how well the lecture is "received". This is further exacerbated by the fact that most of the audience switch off the cameras and therefore only look at black tiles in Zoom. There is no feedback from the audience. Questions are rarely asked as this interrupts the flow of the lecture. The functions in Zoom ("raise hand") are no real help here, as you often cannot keep an eye on them.

A first step away from live lectures over the internet are lecture recordings. In the simplest variants, these are essentially live lectures that are recorded and ideally still edited. From a teaching point of view, the length should be adapted to the usual attention span. Several short videos, ideally with thematically self-contained content, are more effective than a 90-minute recording. This effect is further enhanced if such a short video is followed by an adapted exercise that further deepens understanding.

Lecture videos, with student controllable review, have been rated very highly by students in surveys. The main advantage is seen as an individual learning pace. It is easy to watch parts of the lecture more than once, which is particularly important for very "dense" presentations. However, a big problem, especially with live lectures, is the lack of engagement of the students. Here, cycles of frequent breaks with short video segments should be built in. The students have to be active themselves during the lecture break, be it in discussion groups or with working with smaller tasks.

A completely different approach is the *flipped* or *inverted classroom*. Here, the classic roles of (classroom) lectures and exercises to be worked on independently (usually as homework) are reversed. The contents of the lecture are made available, for example, via course lecture notes or course text. The time in which the lecture would normally have taken place is then used for questions, discussion and working on exercises. The Flipped classes makes it easier to identify basic comprehension problems. The concept can also be combined very well with lecture recordings.

How can one ensure that students regularly study the course text or view the lecture videos? Regular tests or quizzes have proven to be a suitable method here and can be easily achieved in Ilias, for example. Ilias offers a test environment with different types of questions, e.g. single- or multiple-choicefill in the blank questions or questions with free text answers. The evaluation of the test or quiz is done automatically (not recommended for free-text answers). Therefore, the students can receive feedback immediately after completing the test or quiz.

Such tests can be used very well for assurance of the coverage of content. There is (at least) one test or quiz for each chapter of the course text, whereby the questions can be answered with the course lecture notes alone. On average, 1-2 questions should be asked per page of the notes. A deadline for completion ensures that the students "stay on the ball" and do not lose touch with the lecture. In addition, the questions should serve as orientation for the students. On the basis of lecture notes or books, it is often very difficult for beginners to recognise what is really important and what is more of an accessory. This can be controlled a little better by asking appropriate questions. Passing all tests is one of the criteria for awarding credit points. By setting a high minimum score (at least 75%) for passing, one can also ensure that this cannot be passed "by chance". However, this cut-off score requirement should be ameliorated by the possibility of repeating a test (several times).

Experience and research (Force Concept Inventory (FCI), etc.) has shown that students - despite having passed the tests - have only superficially dealt with the content to be prepared. Often, just enough is done to be able to pass the test. Therefore, in the second online semester, we replaced or supplemented these tests with a new tool that promotes a *reflective* engagement with the text content. The students had to keep a kind of *logbook (Reading Log)* [4,5] in which, among other things, certain guiding questions had to be answered. In the first version, Reading Logs, which have already been used successfully at American universities for years, were adapted to the conditions at a German university.

The students should read the prepared part of the course lecture notes or text (at least) twice. After the first reading, the essential contents are then to be summarised in a very short form in key words or by sketches etc. In addition, a glossary should be used to summarise the newly encountered terms and quantities and their definition or a description. In order to arrive at a more reflective engagement with the contents, open questions that have arisen during reading should also be noted. This should focus the perspective for the second reading. After the second reading, the three most important new ideas should be listed again. Furthermore, the new knowledge should be placed in a larger personally meaningful lived context, e.g. possible applications or already known content from other fields. Finally, the students should briefly discuss which new insights have emerged from the rereading and whether there are further questions that should be discussed in the lecture. In addition, the time needed for reading and filling in the logbook should be noted down.

Logbooks are to be submitted via Ilias the day before the lecture. Students will (usually) receive feedback on their logbook before the lecture. In the sense of just-in-time teaching [6], the submitted logbooks are addressed in the lecture. This procedure gives a very good overview of whether the students have really recognised and understood the essential content. Above all, an attempt is made to address the questions in order to illustrate the meaningfulness of the logbooks.

4. Exercises and lab practicals

Exercises live very much from the interaction of the students with each other and with the exercise instructor or supervisor. The socially construction of knowledge is difficult to achieve online.

One way to do this is to work in small groups, e.g. in breakout rooms (BORs) within Zoom meetings. The supervisors regularly switch between the rooms to answer questions and ensure that the work is focused. In the teacher preparation programmes in particular, it has proven successful that complementary tasks are worked on in the BORs. All students then come together in the main session to present and discuss their results. This also leads to a necessary diversity of ideas and improves student attention, as new ideas are explored and valued.

Exercise elements can also be incorporated directly into lectures. This provides immediate feedback on possible comprehension problems. At the same time, students are engaged and do not remain passive in their role as listeners. For example, multiple-choice questions can be used for formative assessment in face-to-face lectures. For this purpose, we have already used software such as ILIAS live voting, *Plickers* [7] or *Kahoot* [8] in face-to-face courses. There are already numerous concept and application questions in multiple-choice formats (concept tests [9]).

In the online courses, some of these tools could be used as well. In addition, we use the survey function of Zoom (Fig. 2), which has the advantage that it is integrated into the Zoom user interface and opens automatically for the students in the foreground. The disadvantage, however, is that no illustrations can be inserted into questions or answers. The Zoom chat proved to be just as frequent a quick means of individual feedback.

The Mural platform offers a so-called "private mode" in which students no longer see what changes other teachers and students are making. This allows individual predictions to be queried and discussed later.

Practical labs are probably the most affected by the restrictions on face-to-face events. The necessary experience in handling equipment in particular can really only be taught in face-to-face events. If limited presence is possible, various stopgap solutions can be found. For example, a kind of "jig saw" is possible, in which students carry out experiments individually instead of in small groups. However, this is very stressful for the supervisors. Therefore, some experiments were carried out with one group member in the lab and 2-3 other students connected via Zoom. Here, however, one must ensure that they have enough meaningful activities to support them and are not just spectators. The evaluation of the experiment results then takes place as in the in presence mode.

An alternative approach tries to use the creativity of the students and guide them into a suitable path to solve content problems. For example, one can assign relatively general tasks (What are the factors which influence the period of a pendulum?), which are then to be solved with the respective means available (e.g. in the household). The students then have to design the experiments themselves instead of working on ready-made experiments, as is unfortunately often the case in

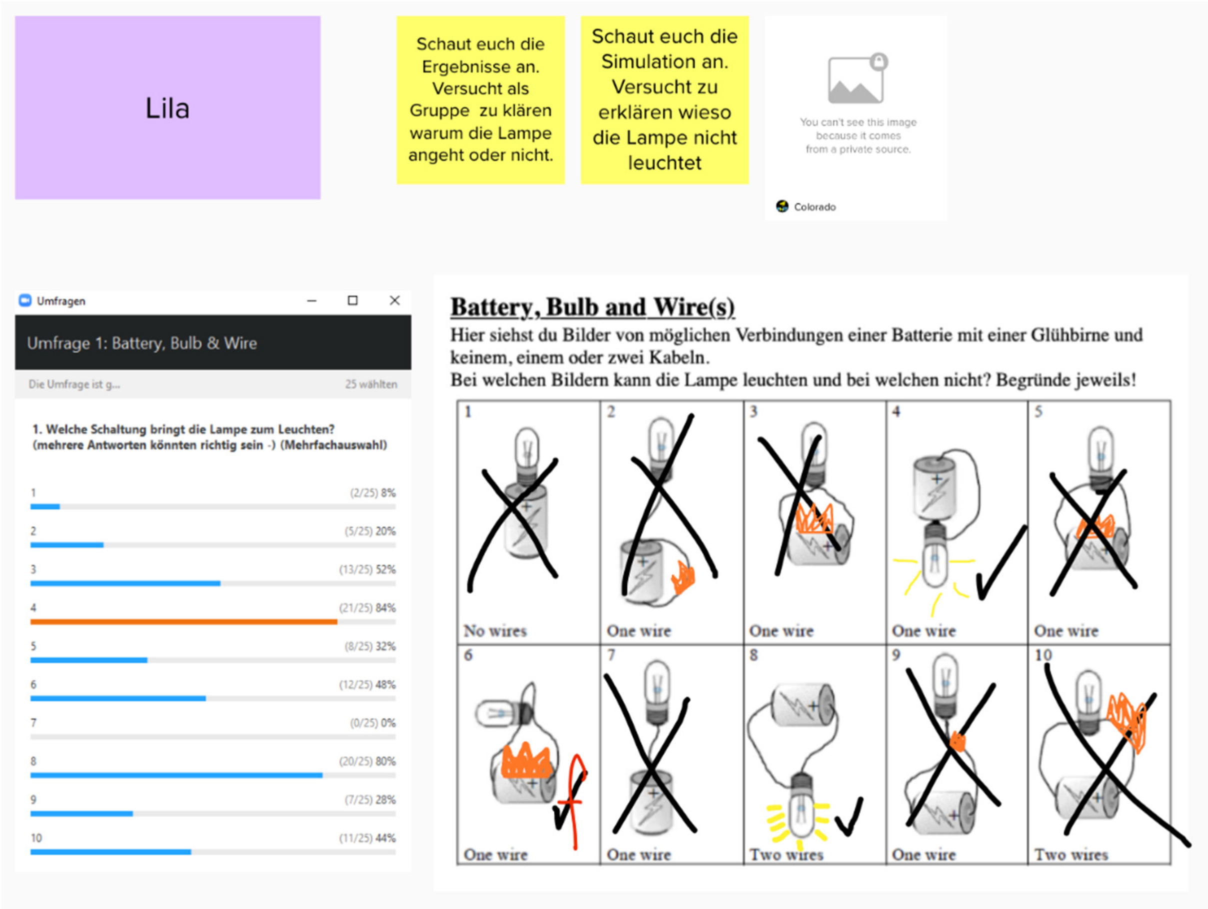

Fig. 2: This enlarged section from Fig. 1 shows the processing of the task "Which circuit makes the light bulb light up? Record your predictions in drawings and check them with the PhET simulation "Switching circuits: Direct Current" [10]." by a group of students in a mural. The highlighted image shows details of a group's processing, e.g. comments recorded on virtual Post-It notes and the result of a zoom poll (left), which serves as a basis for discussion, and the result of the subsequent discussions.

practical lab courses. For such experiments, the possibilities of modern smartphones or tablets, which are equipped with a variety of sensors, can be used very well. These can be read out with software such as *phyphox* [11]. With apps like Vernier's *Video Physics* [12], movements can be filmed and evaluated. These are only two examples of the possibilities offered by the use of smartphones. This is very attractive, especially for students, because it allows them to work on examples from their immediate world. Also, students love to use their cellphones.

Another possibility, which will usually be a supplement rather than a substitute for real experiments, is the use of simulations. For the natural sciences, especially physics, *PhET* [13] is highly recommended here. PhET was founded almost 20 years ago by Carl Wieman, using his Nobel Prize in physics money, and

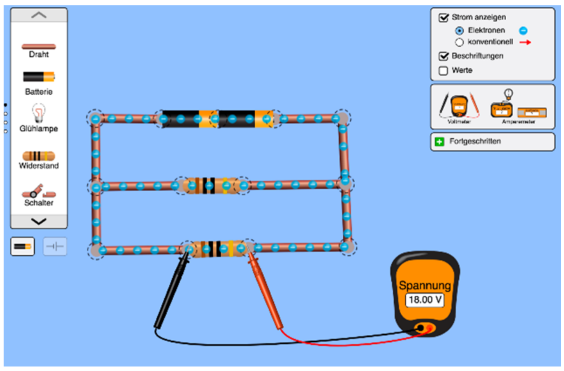

Fig. 3: PhET app for DC circuits [10].

now includes more than 150 simulations with almost 3000 examples of use by practitioners from schools and universities. In addition to simulations from the field of physics, there are also simulations on chemistry, mathematics, biology and the earth sciences. The apps on electrical circuits or optics are very helpful for physics education at university, as their design makes them very close to real experiments. One can perform "real" measurements, e.g. on simple circuits (Fig. 3).

An alternative that is very attractive for students is working with programmable robots. Here we have had good experiences with the robots ("*Codey Rocky*") from *Makeblock* [14] (Fig. 4). These can be programmed with the simple programming language *Scratch* [15], which was developed at MIT especially for younger children. The robots can be equipped with numerous sensors, enabling them to carry out physical projects. We will present a concrete example in section 6.

Fig. 4: A programmable CodeyRocky robot from Makeblock. The robots are movable and can be equipped with various sensors.

5. Examinations

Studying always includes examinations. In order to avoid major delays, it is of course not possible to do without any examination activity for a year or more.

All participants have had good experiences with oral examinations via Zoom (and other video conferencing systems). The procedure here is relatively similar to that of a face-to-face exam. LMS such as Ilias often provide options for electronic tests (see above in the section "Lectures"), usually with the option for automatic evaluation of multiple-choice tests. At first glance, this seems very practical, but it is associated with numerous dangers. The authentication of the participating students can be a problem. The quality of such tests for performance review stands and falls with the quality of the questions and especially the distractors, i.e. the wrong answers offered. To create a good and meaningful multiple-choice test, one must already have a very good idea of the students' prior knowledge ("misconceptions"). One must therefore anticipate the possible errors and choose distractors accordingly. In many areas of physics, the typical students' prior knowledge is very well studied and very helpful, e.g. in mechanics and electricity.

Conducting classical examinations in online formats is inevitably fraught with major problems, especially due to the conflict between the necessary monitoring and the protection of privacy. However, there are ways to manage this balancing act here as well. It should be noted, however, that students know the capabilities of modern media very well and know how to use them for themselves. This has led to large-scale attempts at cheating in less well-designed online exams [16]. Such cheating, e.g. through communication between the participants (including a "division" of the tasks [17]) is also possible in formats such as *open-book examinations, in which* the use of external aids such as books and/or internet sources is permitted.

Fig. 5: Permitted form of video surveillance during online examinations via the camera of a mobile phone.

In consultation with the legal department of the University of Cologne, we have developed a format that enables the holding of examinations with simultaneous video surveillance of the participants within the framework of the legal possibilities. Such monitoring is possible if only one camera is used and the image section preserves privacy [17]. A quick camera pan through the room is also permitted for control before the examination or in cases of suspicion. An illustrative example is shown in Fig. 5. A smartphone, which practically all students have today, is usually used for video transmission. It is mounted in such a way that it allows a view over the examiner's shoulder, always showing the hands and the screen of the computer on which tasks are provided. There are many creative ideas for holding the smartphone that make use of household objects (Fig. 6).

To conduct the exam, the participants are divided into BORs, with a supervisor assigned to each BOR in addition to a participant. The supervisor authenticates the identification of each participating student. The photo id, school id and the matriculation number of the student are compared and matched. Then the matriculation number is compared to the log in data for the examination on the computer screen. The computer is checked for programs and apps with the students sharing their computer desktop via Zoom. The division into BORs makes it possible to transmit the video as well as the sound without disturbing other participants. The participant's microphone is active. This prevents communication with other people who may be in the same room and give unauthorised support. It also makes it easy to ask questions.

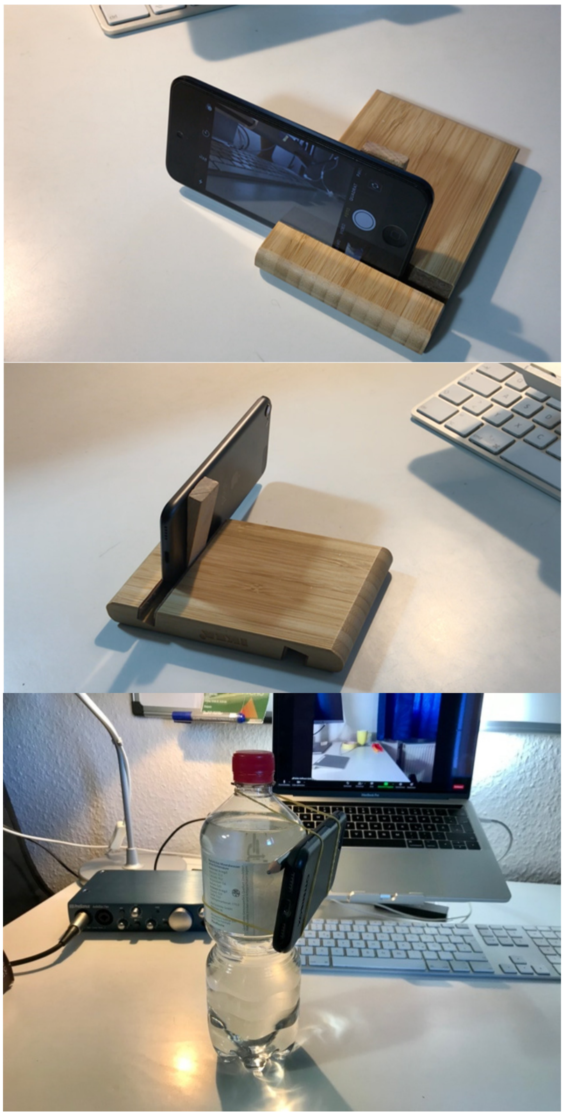

Fig. 6: Excerpt from the instructions for examiners with creative solutions for the self-made holder of a smartphone as a camera. Further ideas can be found in YouTube videos, for example.

The speaker on the side of the participants is also permanently switched on so that questions and comments from the supervisors can be heard. The supervisors only switch on their microphones when necessary, as they monitor several BORs at the same time with several devices.

Of course, even this procedure does not offer 100% security against attempts at deception. But that is not desirable at all! In principle, the online examinations should offer a level of security comparable to that of the classic face-to-face examinations.

We have successfully conducted such examinations several times in the past semester. The students were very cooperative and showed full understanding for the measures. Technical problems occurred only very rarely. They were about as frequent as in classical examinations, where, for example, disruptions in local transport more often lead to students starting examinations late or even missing them altogether.

Furthermore, in the examinations conducted according to the procedure described above, there were no obvious attempts at cheating.

6. Concrete examples

In the following, we would like to demonstrate with some concrete examples how often unexpected positive results can be achieved through online teaching.

In the course "Mathematical Methods", prospective physics teachers at the secondary or middle and high school levels learn the necessary mathematical tools for their studies. In this case, it goes only slightly beyond the usual material in an advanced mathematics course (which, however, is usually only attended by a small proportion of the participants!). This course has been held in the inverted classroom format for many years, with mixed results.

With the switch to an online format, BORs will work with a maximum of 5 people. In each room, a student tutor is responsible for discussing all assignments and resolving any problems. Support staff are available as mentors to answer questions that arise and to provide other assistance. It is evident that students work in a much more focused manner in such a format and the usual attrition in participation over the course of the semester is much less than in the face-to-face version. For example, a significantly higher percentage of students took part in the final exam than in the face-to-face version. This had no influence on the pass rate, which was even slightly better than in previous years.

In a seminar on the use of media in physics teaching, we introduce students to object-oriented programming with *Scratch* [15]. Scratch is a free programming environment that is easily accessible for children and young people and is used all over the world. The students created simple individual programs in Scratch in groups to learn how to use the tool and to understand the objects used in programming. As a transfer task, the students were shown the robot *Codey Rocky* (see Fig. 4) later in the semester, which can be programmed with mBlock5. The mBlock programming environment supports both a Scratch-based and a Python-based version of mBlock. Both programming languages are available free of charge via the mBlock website [18]. The transfer task included a programming challenge in which the students competed against each other in programming teams.

The programming task was first presented in the plenary session of the seminar (Fig. 7). During the rest of the seminar session, the students were able to try out parts of their programmes in BORs of the Zoom event meeting by submitting the programme files to the seminar supervisors via Zoom chat. The supervisors played the programmes on the Codey Rocky robots available in the lab and ran the programmes live in ZOOM, so that the students received more precise feedback on how their programme parts worked and could thus make targeted changes to the code. Based on these tests, the teams had two weeks to complete and submit the challenge programmes. The groups' five completed programmes were uploaded to five different Codey Rockys before the seminar session and could compete live in the Zoom event meeting. For the second part of the semester, some project groups were able to borrow a Codey Rocky and materials to create their project.

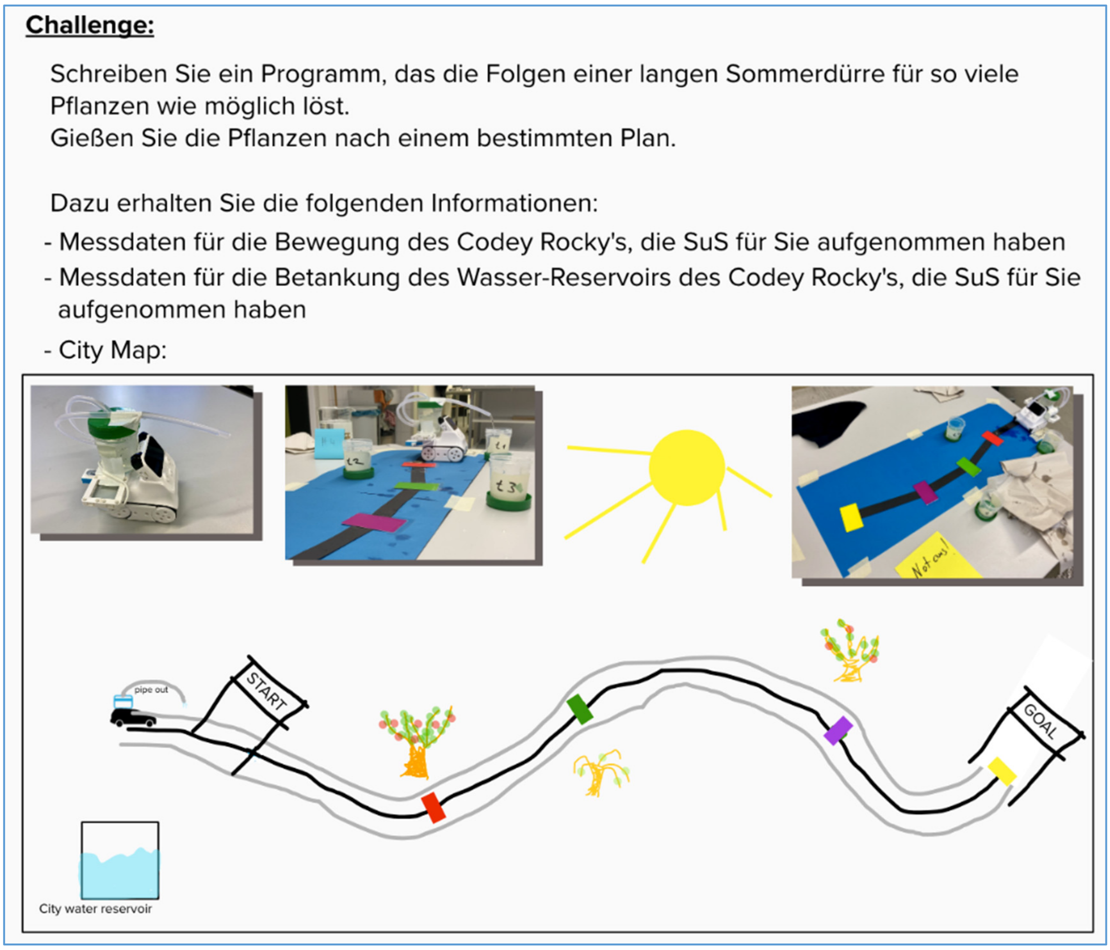

Fig. 7: Programming challenge: profile of the kinematics *task to be solved; Codey-Rocky modified for* pouring water*; test track; carrying out the challenge live in ZOOM.*

7. What will remain?

Will we return to the old forms after the end of the pandemic? We don't think so, because many colleagues have discovered new forms of teaching (inverted classroom etc.) and their advantages during the crisis! This will certainly also be reflected in future face-to-face teaching. Lecture recordings are especially popular with students, as they support an individual learning pace. This tool will remain with us, as many universities have also upgraded to create the technical conditions for it. However, lecturers should make sure that the old recordings are not taken out of the cupboard every year, but that the courses are always developed further. Overall, we expect that face-to-face teaching will remain very important, but will be used more consciously and purposefully. Formats from online teaching will continue to play a role, but in many cases as a supplement rather than as the main form of teaching. This idea of supplementation is supported by the history of instructional innovations like printing, recording, film, TV, internet, etc. not replacing the previous strategies but enhancing.

In our view, the quality of teaching will improve overall as a result of online teaching! This is mainly because many lecturers and teachers have had to come to terms with new teaching concepts and have experienced their advantages in concrete implementation. All of these new ideas and methods help support a wider variety of learners and may support a more inclusive learning environment. On the other hand, online teaching has also shown how important social interactions between students and with teachers are.

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