Lessons Learned 2, 2 (2022)
Submitted: 03. 08.2022
Accepted: 16.11.2022
DOI: https://doi.org/10.25369/ll.v2i2.51
ISSN: 2749-1293 (print); 2749-1307 (online).

Digital Media versus Blackboard and Chalk — Online and Hybrid Teaching in Theoretical Physics

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Abstract

Die Wissensvermittlung in der Theoretischen Physik ist nicht an Demonstrationsexperimente und Versuchsaufbauten vor Ort gebunden. Dies bietet eine erhöhte Flexibilität beim Wechsel zwischen Präsenz- und Online-Lehre. Dennoch sind auch hier einige zentrale Punkte zu beachten. Zum einen sind oft eine schrittweise Entwicklung der Inhalte inklusive Erläuterungen der Dozierenden und Rückfragemöglichkeiten essentiell. Zum anderen müssen viele Rechentechniken und symbolische Schreibweisen erst erlernt und geübt werden. Eigenes Schreiben ist hierfür in der Regel unerlässlich. Beim traditionellen Tafelanschrieb und Mitschreiben in Präsenz werden diese Aspekte automatisch berücksichtigt. Beim Wechsel in die Online-Lehre bildeten wir dieses Format ab, indem wir auf synchrone Veranstaltungen setzten, in denen „live" vor- und mitgeschrieben wurde. Unser Vorgehen evaluierten wir in einer Online-Umfrage. Teilaspekte unserer Herangehensweise werden bei der Rückkehr in die Präsenzlehre weiterhin von den Studierenden bevorzugt, insbesondere eine digitale Ausführung des Live-Anschriebs. Dies unterstützt hybride Lehrformen, die gleichzeitig in Präsenz und online stattfinden, was sicherlich einen wesentlichen Aspekt der zukünftigen Entwicklung universitärer Lehre darstellt.

Knowledge transfer in theoretical physics is not tied to on-site demonstration experiments and experimental setups. This offers increased flexibility when switching between face-to-face and online teaching. Nevertheless, there are some key points to consider here as well. On the one hand, a step-by-step development of the content, including explanations by the lecturer and opportunities to ask questions, is often essential. On the other hand, many calculation techniques and symbolic notations must first be learned and practiced. Writing on one's own is usually indispensable for this purpose. With traditional blackboard writing and taking notes in presence, these aspects are automatically taken into account. When we switched to online teaching, we replicated this format by relying on synchronous events in which "live" writing and taking notes were implemented. We evaluated our approach in an online survey. Several aspects of our format were still preferred by the students when returning to face-to-face teaching, especially a digital version of live writing. This supports hybrid forms of teaching that take place simultaneously in presence on site and online, which is certainly an essential aspect of the future development of university teaching.

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This article was originally submitted in German.

1. Introduction

When studying physics, theoretical physics represents an essential pillar of education. Unlike experimental physics, which derives laws of nature from experimental observations and measurements, a mathematical description of reality is derived from a few mathematically formulated axioms using mathematical methods. Thereby, a quantitative predictive power arises. The quality of a theory is assessed by comparing the results to experimental measurement results.

This already reveals essential requirements and skills that must be taught and learned in the context of theoretical physics. For example, these are logical and step-by-step successive derivations of mathematical relationships and conclusions based on fundamental, mathematically formulated assumptions. At the same time, appropriate calculation techniques and the corresponding notation must be learned and practiced. A high degree of precision is required when performing corresponding calculations.

Our presentation refers to our teaching activities at Otto von Guericke University Magdeburg in the four-semester period from the winter semester 2020/2021 to the summer semester 2022. Our courses in this period were alternately taught in presence under appropriate hygiene regulations, via fully digital online teaching, as well as in a hybrid format in which teaching took place simultaneously in presence on site and online. These developments allow us to report here on a wide range of experience with different formats. At the end of the winter semester 2021/2022, we conducted an evaluation to get quantitative feedback from the students on the formats we used and their general impressions.

In the following, we refer to eight courses in the field of theoretical physics carried out by our department in the mentioned four semesters. Four of these courses are assigned to the bachelor program in physics [1] and four to the master program in physics [2] at Otto von Guericke University Magdeburg. In detail, these were the courses Theoretical Mechanics (in Magdeburg submodule 1 of the module Mechanics and Electrodynamics, Physics Bachelor [1], extending over two semesters), i.e. the study of the motion (and statics) of material bodies in space under the influence of known forces – twice; Theoretical Electrodynamics (in Magdeburg submodule 2 of the module Mechanics and Electrodynamics, Physics Bachelor [1], extending over two semesters), i.e. the teaching of the motion of electric charges in space as well as the interaction with and temporal change of electric and magnetic fields, including aspects of special relativity – twice; Hydrodynamics and Elasticity (in Magdeburg submodule of the double module Compulsory Elective Courses with corresponding specializations, Physics Master [2]), i.e. the study of the flow of fluids and the deformation of elastic solids – twice; Theory of Polymers (in Magdeburg submodule of the double module Compulsory Elective Courses with corresponding specializations, Physics Master [2]), in particular the statistical description of properties of single linear polymer molecules and polymer melts – once; Statistical Mechanics in Non-Equilibrium (in Magdeburg submodule of the double module Compulsory Elective Courses with corresponding specializations, Physics Master [2]), especially on the classical theory of linear response, on statistical methods in the framework of Langevin and Fokker-Planck equations, and on classical density functional theory – once. The temporal frame of these courses amounts to 6 hours per semester week (Bachelor courses) and 3 hours per semester week (Master courses), respectively. Two thirds of these hours are spent on lectures, one third on discussions of exercises. The admission to the module examinations is acquired through performance certificates (e.g. successful completion of exercises, written or oral tests). The module examinations for all these courses are oral.

2. Teaching before the pandemic

Before the developments associated with the Covid 19 pandemic, teaching in theoretical physics was largely carried out in the classical classroom format. As already mentioned at the beginning, in most cases traditional blackboard instruction was used. This form of teaching serves many of the requirements already mentioned in this context.

First, the teaching content is developed step by step through "live writing". Causal chains and calculation steps that build on one another can be conveyed particularly well in this way. The writing activity of the lecturer automatically adjusts pace. In addition, with a sufficiently large board, the previous calculation steps remain present for longer times and are available in the further course of the lecture, so that reference can be made to them if, for example, intermediate steps in previous calculations are used at a later point. Oral explanations of the calculations by the lecturers are often perceived as essential, as is the possibility for the students to immediately ask questions.

An essential part of education in theoretical physics is to learn how to perform complex calculations independently. For this purpose, it is necessary not only to be able to understand calculations logically, but also to learn the calculation techniques themselves, including the symbolic notation used. These techniques usually have to be practiced by writing them by oneself. The transcript in face-to-face courses offers a first step into this direction. In fact, a clear majority of students in our courses usually grasps the opportunity to take notes. Already before the development of the Covid 19 pandemic, we made our lecture notes available online to students after the respective event date. This allows the transcript to be cross-checked for any ambiguities or possible typos. In addition, students who were unable to attend events in person can access the content.

Exercise assignments timed to the lecture content were available online and were also distributed as hard copies in the past. Depending on the course, solutions were submitted on paper and graded. In the exercise courses, the solutions to the exercises were presented and discussed on the blackboard by students or lecturers.

Depending on the course, different contributions had to be made to performance records in order to gain admission to the module examination. In particular, these were a certain proportion of successfully completed solutions of exercises, presentations of solutions in the exercise courses (depending on the course), and written performance tests in presence. In particular, calculation skills had to be demonstrated. The module examinations of all mentioned courses are to be carried out in oral form in Magdeburg. Here, mainly content-related knowledge and understanding are tested as well as knowledge of central formulas and very short calculations. These individual examinations in presence usually took place together with an assessor at a table, writing on a sheet of paper.

3. Switch to online teaching

Our course in the Physics Bachelor started in the winter semester 2020/2021 under appropriate hygienic measures in presence. The classic blackboard served as the medium for transferring knowledge. However, due to the development of the pandemic, a change to digital media and online teaching became necessary after a few weeks. Accordingly, our courses were held entirely online for the remainder of the winter semester 2020/2021 and the entire summer semester 2021.

For the reasons outlined above, we set ourselves the goal of replicating as far as possible the experience of writing on the blackboard in presence with the possibility of taking notes when switching to digital formats. We also intended to provide the possibility of asking questions in real time. Therefore, we chose the format of synchronous online live events. At Otto von Guericke University Magdeburg, Zoom video conferencing software was and is available for this purpose [3]. Other frequently used formats are, for example, the discussion of previously prepared and completed slides, lecture notes, and solutions to exercises in video conferences; the provision of pre-produced videos for independent asynchronous study, supplemented, if necessary, by additional synchronous question sessions; or the provision of scripts and solutions prepared for independent, self-reliant study with subsequent online discussions. All of these formats offer their own advantages. However, due to the subject-specific characteristics of teaching in theoretical physics as described above, we found the implementation as synchronous online live events with "live writing" to be the most suitable.

To realize such a digital format, we purchased active displays with pen input, in our case Wacom Cintiq 16 [4]. In the online lectures, we used simple graphics programs to create long blank pages that could be viewed by all participants in the video conference by means of Zoom ("screen sharing"). The script was written live on these pages. As on the blackboard in the lecture hall, the previous calculation steps were available in longer derivations and could be referred to by scrolling back. Color markings as a very simple but effective aid were also possible. Care was taken to give students sufficient time to note down the content before the written lines disappear by scrolling on. As an advantage compared to the use of the blackboard in the lecture hall, the documents can be saved at the end and are still available in later lectures, for example in case of queries, ambiguities or reference to earlier derivations. Intermediate questions by students were always possible and encouraged. In practice, there was often a lively dialogue that could hardly be distinguished from corresponding experiences in the lecture hall in presence, even though almost nobody of the students used a camera. The lecture notes were made available to the students online after the events. For this purpose, the central e-learning platform (Moodle) at Otto von Guericke University Magdeburg was used [5,6]. As a rule and outside of examination times, most students attended the online lectures.

The events for discussing the exercise tasks were conducted in the same format and differed only in that the digital whiteboard of the Zoom conference software was used directly for writing. Here, no continuous scrolling but page turning is implemented. Due to the clearly defined tasks, this is sufficient. Since only a few participants had the necessary technical equipment, the students did not present their calculations, in contrast to classroom teaching. This task was completely taken over by the exercise instructors. The possibility to ask questions directly about individual calculation steps, which is particularly important in the exercises, was still available and was used intensively. In general, the discussion of the exercises took place in the online plenum and not in Zoom breakout rooms.

In the courses for the Physics Bachelor, the performance certificates consisted of successfully completed exercises and written interim tests. The exercises were made available digitally via the e-learning platform. After a processing period of approximately one week, the solutions were uploaded by the students in digitized form, for example as a scan or photo. The e-learning platform also allowed digital commenting and evaluation of the uploaded solutions, whereby the comments and evaluations could be viewed by the students. The written midterm tests were also administered via the e-learning platform. At a specific time, the assignments were released, and the students then had a set amount of time (60 or 80 minutes, depending on the test) to complete the assignments at home. In addition, 20 minutes were allotted for digitizing and uploading the solutions. In this process, students were required to work independently and no aids were allowed. We emphasize here the high degree of honesty and sincerity among the students during this procedure. Except for a few unclear individual cases, we could not detect any obvious deviations from the specifications or attempts of cheating. Nevertheless, we will conduct the interim tests in presence again in the future, if possible. In the courses for the Master's degree in physics, the performance certificates consisted of oral tests, which were conducted similarly to the module examinations described below.

The module examinations for all listed courses take place orally in Magdeburg [7]. In digital formats, these oral examinations were also realized using the Zoom video conferencing software. For questions that could be answered orally, this posed no problem. For questions that required short written calculations or formulas as answers, they could be written on a piece of paper with a dark pen similar to corresponding face-to-face oral exams. They were then held up to the camera. We did not experience any problem during this procedure. Some students were already equipped with devices for digital input via pen and were of course allowed to use them.

4. Transition back via classroom teaching to subsequent hybrid teaching

The winter semester 2021/2022 started at Otto von Guericke University Magdeburg again with classroom teaching. This was maintained for a

longer period of time. It was not until the pre-Christmas period and especially with the turn of the year that our courses were switched to hybrid formats. This meant that we continued to offer face-to-face courses. However, students could also participate digitally and decide freely.

The transition from face-to-face to hybrid teaching in the lecture was relatively unproblematic for us. Building on the equipment for online teaching, we carried out live writing in the lecture room using digital means. The input was achieved via input pens and active displays connected to a laptop for presentation via LCD projector. In other words, the previously tested online format of synchronous digital live writing was now implemented in the lecture room.

At the same time, the writing surface on the laptop was shared via Zoom video conferencing software as a synchronous online event. According to the students, the laptop microphone and camera provided sufficiently good sound and image quality. Students were free to decide whether they followed the lecture in presence in the event room or digitally as a synchronous online event, with identical content delivered via live transmission. Both variants were accepted by the students, sometimes in alternation. It is particularly positive to note that even in this hybrid variant, students continued to ask questions leading to discussions even across the boundaries of online and face-to-face participation.

For the submission of the exercise solutions and their correction, we continued to use the digital procedure via the e-learning platform [5]. The discussion of the exercises continued to take place in presence, whereby a sufficiently large lecture hall could be found. This made it possible for the participating students to present their solutions and to discuss them directly and ask questions. The solutions were also made available via the e-learning platform. We conducted the written interim tests simultaneously in presence and digitally via the e-learning platform according to the procedure described above, whereby the students were free to choose between the two variants. Both variants were used in roughly equal proportions. Our comments above on the honesty and sincerity of the students continued to apply. Correction and assessment were again carried out via the e-learning platform, for which we digitized the analog solutions submitted in presence.

5. Return to classroom teaching

In the summer semester of 2022, most of the courses at Otto von Guericke University Magdeburg were again held in presence under appropriate hygiene measures. This includes the courses we offered. We gained the central insight for us when we asked the students which format of presenting the contents they would prefer in the face-to-face courses. They could choose between digital input via a display using an input pen, laptop and LCD projection on the one hand, and, on the other hand, the classic blackboard format.

Surprisingly for us, the majority of the students surveyed were in favor of digital live writing via LCD projection in the classroom, as opposed to the classic, analog blackboard variant. The reasons given were, for example, better readability and better visibility of the higher projection surface from the back rows. However, the main point that seemed to be important to the students was that the lecturers in the projection variant continuously face the students throughout the writing process and do not turn their backs to them in the meantime when writing on the blackboard (see also the evaluation results below).

On the side of the lecturer, it should be noted that the digital version is significantly less physically demanding. However, the set-up and dismantling times before and after the lecture are noticeably longer (approximately 10 – 15 minutes each) when compared to writing on the blackboard. Overall, these findings have led us to switch to the digital variant via LCD projection in the lectures since then.

In this way, routines developed during online teaching are now likely to find their way into on-site classroom teaching in the longer term. A significant advantage of this approach is the continued uncomplicated possibility and flexibility to conduct the events in a hybrid fashion. Consequently, students are provided with the

opportunity to participate even if they, for various reasons, are prevented from attending events in person. This offer is frequently accepted, whereby we perceive a preference of the majority of students for participation in presence.

6. Evaluation by the students

In order to obtain a more detailed assessment of the situation of the students and the teaching formats we provide, we conducted an online survey via e-learning platform at the end of the lecture period of the winter semester 2021/2022. The anonymized response included 17 participants. At least, some tendencies can be inferred from this response. Not every question had to be answered, which explains the fluctuating numbers in the results presented below. The evaluation compared different teaching formats, but also asked questions about, for example, learning success in online teaching, dealing with reduced social contacts, and the learning environment.

First, we compared different teaching formats, distinguishing between five types:

- Format 1: Face-to-face event with classic live writing on the blackboard. Remarks on this traditional format were included above.
- Format 2: Synchronous online event via digital live writing. This format corresponds to the digital variant that we use. Comments on this format were likewise included above. We refer to it as a synchronous event because students and lecturers meet simultaneously in a video conference and thus communicate in real time.
- Format 3: Synchronous online event using previously prepared media, for example, discussing PowerPoint slides or scrolling through a lecture script with simultaneous oral explanation by the lecturer. Even if individual digital notes are inserted, live transcription is not the focus here.
- Format 4: Asynchronous online event. In this case, the instructors prepare digital materials and make them available to the students online. The students are free to decide when exactly they want to access and work through the materials. Examples of this format are recorded videos of lectures with blackboard notes, recorded discussions of PowerPoint slides or lecture notes, i.e. formats that to a certain extent emulate synchronous events but can be accessed asynchronously and also repeatedly.
- Format 5: Self-reliant study of lecture material. With this format we refer to working independently (asynchronously) through traditional learning materials such as lecture notes, solutions of exercises or book chapters.

The central criterion for us in evaluating the listed formats was the learning success of the students. Therefore, we asked the students for their assessment of the different formats (formats 1, 3, 4 and 5 in the list above) relative to the synchronous online format with live writing (format 2) that we chose. On the one hand, we asked students about their subjectively perceived learning success, i.e. independent of actual feedback through credits achieved in performance tests or results in module exams, see Fig. 1. On the other hand, we asked them for an assessment of their learning success based on actually provided feedback, see Fig. 1 as well.

It is clearly evident here that the responding students rated their subjective learning success worse on average in our synchronous online format with live writing (format 2 in the list above) than in the traditional face-to-face event (format 1 in the list above), see Fig. 1(a). This statement is almost neutralized when students include actual feedback such as scores achieved and exam results into their response. In fact, on the instructor side, we did not find a drop in learning success among students on average during performance assessments and exams compared to our longer-term teaching and exam experience prior to the pandemic.

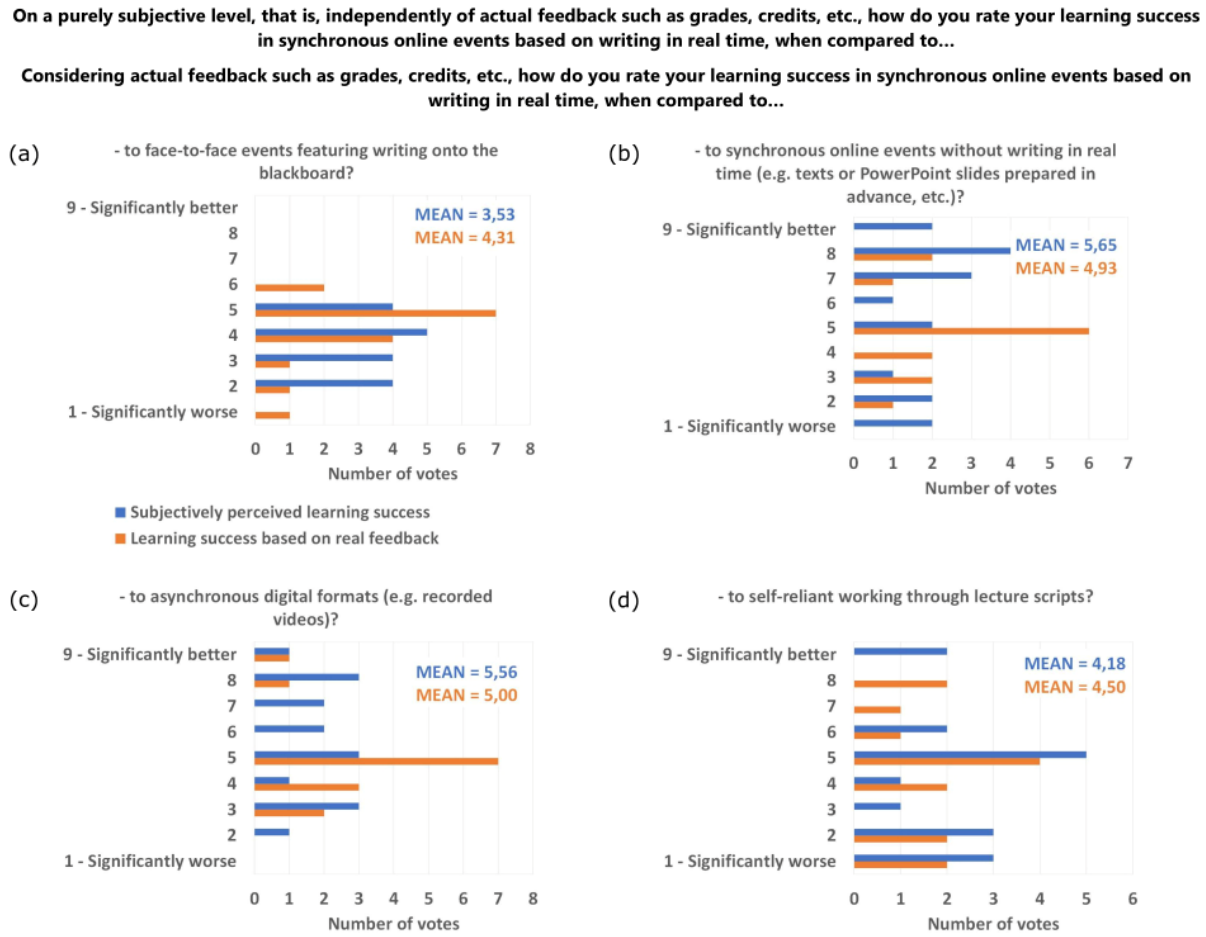

Fig. 1: Students' assessment of their perceived learning success in the synchronous online format with live writing offered by us relative to other teaching formats, namely (a) the classic face-to-face format with blackboard writing, (b) synchronous online formats without live writing but using slides, scripts and similar documents prepared beforehand, (c) asynchronous digital formats such as recorded videos, and (d) independent and self-reliant study of provided materials such as scripts or book chapters. The students' feedback was based on their subjective impression (blue) on the one hand and actual feedback such as exam results (orange) on the other hand.

The other synchronous and asynchronous online formats (formats 3 and 4 in the list above) were rated on average by the students as less successful in this respect compared to the format we chose, see Fig. 1(b) and (c). It is striking that working through the provided scripts independently and self-reliantly (format 5 in the list above) was perceived as comparatively more successful on average, see Fig. 1(d). However, this assessment is neutralized when the actual feedback that the students received on their performance is included. Overall, the survey results give the impression that the chosen combination of synchronous online course with live writing and additional online provision of lecture notes and solutions to exercises is a sensible variant in online teaching.

Since we assume that the students' (perceived) ability to concentrate on the contents is related to their subjective learning success, we surveyed them regarding their ability to focus during the different formats, see Fig. 2. The survey was conducted in absolute terms for the five formats mentioned above, not relative to our online format.

On average, the responding students felt the strongest ability to concentrate in face-to-face courses with blackboard writing, followed by the synchronous online format with live writing that we selected. Interestingly, the teaching format of the synchronous online event with previously prepared materials without live writing (frequently used in other courses) received the worst average rating with regard to the ability to concentrate. Asynchronous

online courses and working through scripts on one's own were rated better on average with regard to the ability to concentrate than synchronous online courses based on materials prepared beforehand.

Another indication that several students link face-to-face formats with increased ability of concentrating is the rate of in-person attendance during contributions to written performance assessments. Thus, about 50 % of the students repeatedly participated in presence although an alternative (non-supervised) online variant was offered. Specifically, the students referred to their increased focus.

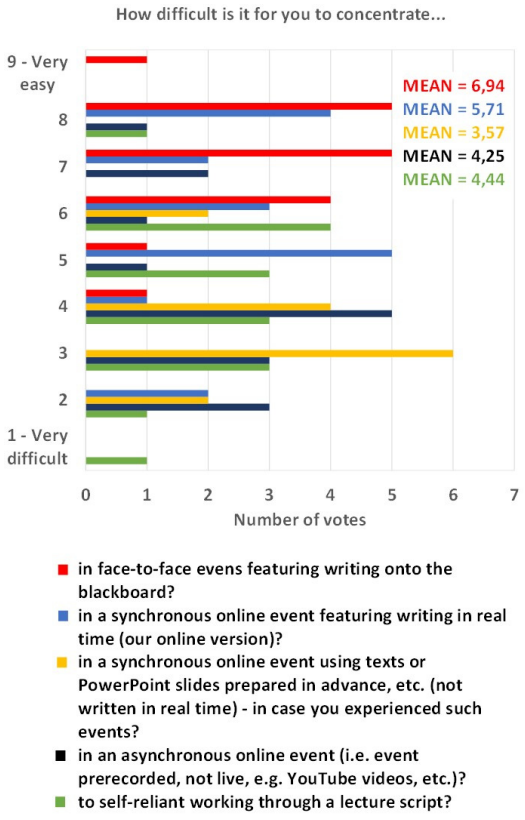

Fig. 2: Students' assessment of their ability to concentrate and focus in the different teaching formats.

In connection with the ability to concentrate during online courses, it was still important for us to find out to what extent it was at all possible for students to find an appropriate environment for following digital courses when taking into account their personal living situation.

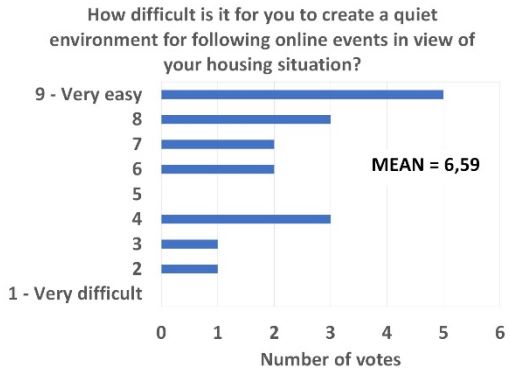

Fig. 3: Feedback from students regarding their ability to create a quiet learning environment with respect to their living situations.

As can be seen from Fig. 3, a significant proportion of students cannot easily establish a quiet environment in their current living situation. This problem is probably difficult to solve by adapting online teaching formats and argues strongly for at least hybrid formats in which at least some of the students can participate by being present on site.

Above we already mentioned that we consider the possibility for students to ask direct questions during lectures to be an extremely important component. Therefore, we wanted to find out whether the students experience an increased amount of inhibition to ask questions in events of online teaching. Here, the majority of students stated that they felt more inhibitions in this respect in the synchronous online formats than in face-to-face courses, see Fig. 4.

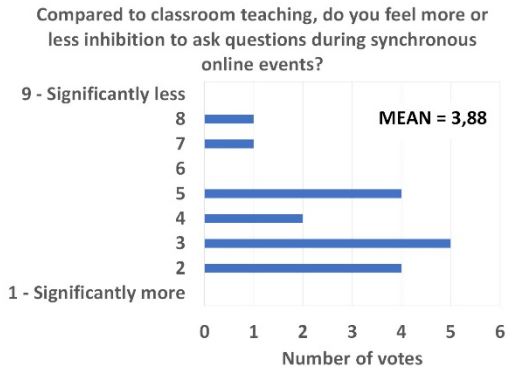

Fig. 4: Personal inhibition to ask questions during our digital format when compared relatively to face-to-face teaching on site.

Furthermore, it is not surprising that most students during online teaching miss the direct social contact with their fellow students, see Fig. 5.

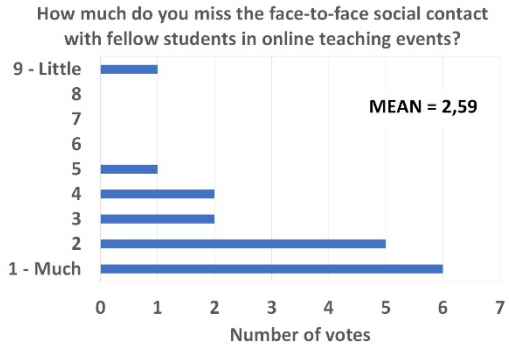

Fig. 5: Feedback on subjective perception of lack of social contact with fellow students during online teaching.

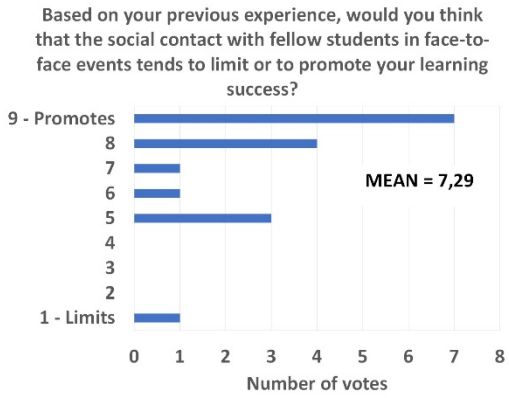

Fig. 6: Students' assessment of the impact of social contact with fellow students in face-to-face on-site events on their learning success.

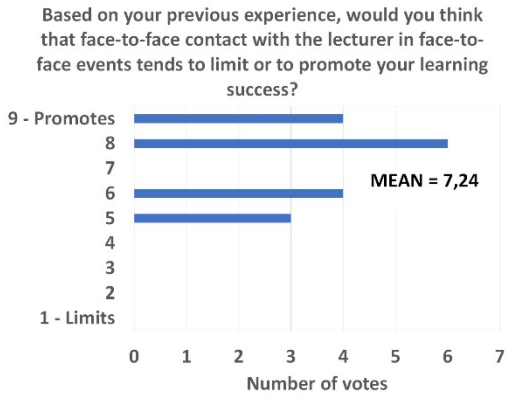

Fig. 7: Students' assessment of the impact of face-to-face contact with lecturers on their learning success.

It is interesting to note that the students assess this missing component to be partly responsible for their on average subjectively perceived reduced learning success in online formats, see Fig. 6. The lack of face-to-face contact with lecturers also reduces learning success according to the students' assessment, see Fig. 7.

Overall, we wanted to find out how students evaluate the synchronous online formats based on live writing that we offer, when compared to traditional face-to-face formats with blackboard writing. We expected a clear difference between lectures on the one hand and events on the solutions of the exercises on the other hand, as the latter usually more substantially rely on in-person discussions.

In fact, the majority of the students prefer face-to-face formats on-site for the exercise courses, see Fig. 8. In contrast to that, concerning the lectures, while taking all aspects into account, the students on average consider the synchronous online format with live writing as basically equivalent to the traditional face-to-face format, see also Fig. 8. We consider the latter to be a success of our implementation of online teaching in this area of theoretical physics. At the same time, it opens up corresponding possibilities for the design of future teaching formats.

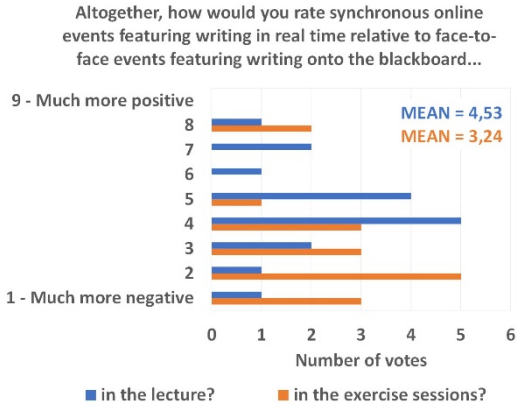

Fig. 8: Taking all aspects into account, comparison by students of digital online teaching via live writing with ordinary face-to-face teaching via blackboard writing, distinguishing between lecture and exercise courses.

Finally, the question arose for us as to whether elements of online teaching should also be adopted in the future after returning to face-to-face teaching or in hybrid teaching formats. As already mentioned above, the majority of students were in favor of live digital writing via LCD projection when compared to traditional

blackboard writing during face-to-face teaching. Figure 9 shows the corresponding results of the survey.

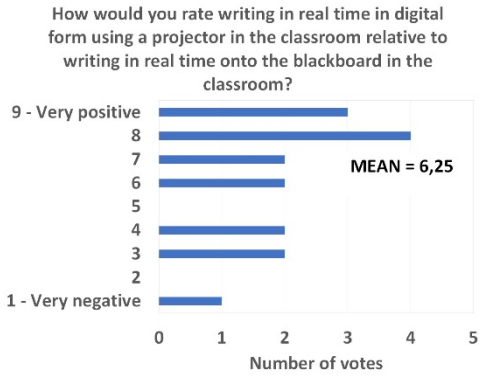

Fig. 9: Student evaluation of live digital writing in combination with LCD projection during face-to-face on-site teaching relative to typical live writing on the blackboard.

The reasons provided were the easy integration of digital elements such as images or web pages as well as the permanent access to the contents already discussed in case of later questions, in addition to the better readability and visibility already mentioned above as well as the uninterrupted facing of the lecturers to the students.

7. Our own assessment

Students are at the center of teaching. Their perspective has been described in detail in the previous section. Nevertheless, we would like to briefly summarize our own impressions as well.

We have already mentioned that setting up and dismantling the technical equipment in addition to starting and stopping the video conferences in the on-site teaching rooms takes around 10 to 15 minutes of time before and after each event in the case of digital live writing, in contrast to classic blackboard teaching. If successive courses are scheduled tightly, this can lead to conflicts. In particular, concluding discussions of a few minutes after the end of each event, which otherwise often develop, then suffer. Yet, there is a little bit more time available during the courses compared to blackboard writing, because there is no need to wipe the board.

From our point of view, there is another, possibly essential aspect that may have contributed to the very positive development of our courses as described above. While the courses were taking place in presence on site for at least a few weeks at the beginning of each winter semester, almost all students and lecturers were able to get to know each other in person. It seems plausible to us that communication barriers in the online mode were lowered in this way, which contributed to the lively exchange even during purely online teaching. In particular, students were not required to use their cameras during online events. A lack of initial face-to-face contact would probably have led to a very anonymous atmosphere as a result. This aspect should be further explored in the future, if necessary. It might generally be useful to hold at least one initial face-to-face event at the beginning of each semester, even in the case of purely online teaching.

We were not surprised that students perceived face-to-face formats in the exercise sessions as more important than in the lectures. On the side of the lecturers, the lack of possibility to directly visually recognize the reactions of the students was more noticeable when the cameras were switched off. As a result, in-depth questions and discussions arose less frequently in the online exercise events than during teaching on site. The online submission of the solutions to the exercises mostly worked smoothly, although corrections via the e-learning platform required some more time when compared to paper submissions. Overall, we did not notice any substantial reduction in students' performance when working on the exercise assignments compared to face-to-face formats. The same is true for other contributions to written performance tests. The necessary archiving of corresponding contributions in digital formats is comparatively easy. In fact, we plan to maintain the digital procedures for the submission and assessment of completed exercise assignments. We will continue to make lecture notes and solutions to exercises available online via the e-learning platform.

The most important new finding for us from the evaluations is that the majority of students also prefer digital live writing with LCD projection to blackboard writing in the face-to-face courses on site. We would have expected this

to be different. Actually, we had assumed that our writing on the blackboard would be more appealing, which was evaluated differently by students on several occasions on average. Therefore, at least in the lectures, we plan to use the format of digital writing in combination with LCD projection more extensively in the future, as far as the technical and temporal possibilities allow. In the exercises, this format is less practicable when different students present their solutions during each event.

Overall, we are pleased that despite the given circumstances associated with the Covid 19 pandemic, we were able to offer students digital online and hybrid formats that received a positive response. It was worthwhile to try to consider the situation and necessities from the students' point of view at the beginning of the transition to online teaching and to draw resulting conclusions by implementing the chosen format. In general, our impression is that the success of studies in online formats depends even more on the motivation and personal responsibility of the students. The fact that most of them successfully met these requirements was clearly evident, for example, from the aforementioned sincerity in unsupervised parts of the written performance assessments. We are therefore very pleased that, on average, the performance of the students in our courses, as far as we can judge, was not affected by the given circumstances of the Covid 19 pandemic.

8. Lessons Learned

We assumed that a step-by-step development of the contents including explanations by the lecturers with possibilities for immediate queries, combined with the motivation to write down the formulas and calculations, are integral parts of teaching in theoretical physics, at least in the context of the courses we conducted. Overall, we see these assumptions confirmed. The positive feedback from students leads us to conclude that mapping such an approach to digital teaching also establishes a useful and successful teaching format in theoretical physics. Therefore, we will continue to give preference during digital teaching to synchronous online formats with live digital writing via video conferencing.

The most surprising finding for us is that the majority of students also prefers digital live writing via active display by input pen, laptop and LCD projection to traditional blackboard writing in face-to-face formats on site. This is significant because it facilitates the transition to different hybrid formats, for example, face-to-face lectures in the lecture hall combined with synchronous online transmissions via video conferencing. Such formats are likely to gain growing importance in the future, also because they increase flexibility on the students' side and may be better able to accommodate individual situations. It is possible that even in purely online formats, initial meetings in presence may have a positive influence on the further course.

In online events dedicated to discussing solutions of exercises, synchronous formats with live digital writing via video conference were preferred as well. Here, however, the implementation as face-to-face on-site events seems more urgent than in pure lectures.

Overall, we as lecturers may place great trust in the motivation, willingness to perform and sincerity of the students. In our case, this became particularly clear from their conduct during the unsupervised written performance tests.

Acknowledgement

A. M. Menzel gratefully acknowledges funding from the German Research Foundation (DFG) through the Heisenberg Program, project number ME 3571/4-1.

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