

Concept of the lecture

'Physics of Molecules and Solid-State Physics 1'

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<https://ep3.uni-bayreuth.de/lecturenotes>

May 18, 2022

Formally, this is a compulsory lecture in the Bachelor's degree programme in physics and teaching physics at high school with 4 hours per week lecture and 2 hours per week exercise groups with 8 credit points. About 35 students take part. The exercises are supervised by 3 assistants. We have formed 6 fixed working groups to which an assistant is permanently assigned. The groups work together in the exercises and also in the plenum (formerly known as lecture).

There are two central concepts '*flipped classroom*' and '*one topic per week*'. Flipped classroom describes the outsourcing of knowledge transfer to the self-learning time before the face-to-face course. In the latter, higher competences such as comprehension, application, synthesis and assessment are then practised. The exercise groups then offer another opportunity to try out the competences on more complex tasks and to clarify final ambiguities in a small group. 'One topic per week' means that students only need to have one topic in mind at any given time. This is in contrast to the usual exercise mode, where the exercise sheet follows the lecture, and is in turn followed by the discussion of the exercise sheet. At each point in time, there would be three topics: that from the current lecture, the sheet from last week and the solution to the sheet from the week before, i.e. the lecture from a fortnight ago.

Timing

'One topic per week' assigns a recurring activity to each day of the week. Due to the traditional dates of the lecture, this was this semester:

Saturday and Sunday Students read the chapter in the lecture notes and watch the lecture videos on it. For self-monitoring, there is an online quiz and partially questions in the script. The objectives to be achieved are described in the script. The exercise sheet concretises these goals with tasks to be solved. Questions about the script can be asked online in 'Perusall' and will be answered by me promptly.

2 Konzept

Monday and Tuesday On the dates of the lecture, the plenum takes place. We first discuss any open questions. Afterwards we discussed 'ConcepTests'-like tasks with the aim to find further ambiguities and already achieve some of the goals.

Tuesday or Wednesday The exercise groups meet with their tutor and work on the exercise sheet similar to a learning centre. The tasks do not have to be solved at the beginning or at the end of the group session. The tutor answers questions but does not give a model solution.

Thursday With the end of Thursday, each exercise group submits a joined solution of the exercise sheet online. The tutors look at the solution but do not correct it.

Friday Videos with explanations of the model solution are released for 7 days. Each group receives the solutions to the tasks they have worked on. The students themselves compare their solution with the model solution. This assessment of adequacy is the highest level of Bloom's Taxonomy! Questions and ambiguities are clarified in the next plenary or in the next exercise group meeting.

Details of the phase before the plenary

I have created a *script of lecture notes* that is very close in scope and sequence to what is typically written on the blackboard in a live lecture. It is more or less the LaTeX version of my handwritten notes on the lecture and the transcription of what I would have said when writing on the blackboard. The script thus conclusively covers all the contents of the course, but it is of course much more compact than any textbook. Using a textbook as a substitute for the script has not proved successful in previous years, as it still seems to be (too) much effort for students to filter out the relevant content, despite the instructions. The script is available online and students can follow when and where changes are inserted.

Then I created *lecture videos* in which I talk about the content in the style of a lecture. I show, underline and draw in the lecture notes. The software I use is ExplainEverything. There is no camera image. I try to show the connections and big lines in the videos. The details are in the script. I am more concise in the videos, shorter than I would be at the blackboard, and repeat myself less often, don't take breaks to copy, tend to talk faster. So about 2x 90 minutes of lecture becomes about 60 minutes of video. Each section in the script becomes a video snippet of about 7 minutes on the university's multimedia server. The possibility of pausing at different points, slowing down, rewinding, reading up on the script is, in my opinion, much better than any live presentation of the same content. The statistics show that virtually all students watch the videos before the corresponding live session.

When working through the script and the videos, *questions* can arise. In the previous year, I used 'frag.jetzt' to collect questions anonymously. About half of the questions were comprehension questions, the other were clues to typos, mostly in the formulas of the script. This year I used 'Perusall' for

discussion on the text. I answer questions whenever I have time, about once a day.

For each chapter, I define *objectives* such as "You will be able to explain rotational spectra of molecules in the gas phase and determine properties such as bond distance or atomic mass from them." Firstly, it is important to me that the objectives are concrete and describe actions. 'Understanding' is too vague. For another, I try to always include the analysis of experimental data, since this is, after all, the core of an experimental science. With the objectives, I describe the extent and depth to which the students are to work on the content and what is to be achieved in the process. The objectives are addressed in passing in the live session. In the future, I would like to give them a more central role.

In addition to the defined objectives, there is an online multiple-choice *quiz* on the elearning server for each chapter of the script for self-monitoring. With four to five questions, students can find out whether they have acquired the expected subject knowledge, i.e. whether they have found the relevant points in the script. The quiz thus only targets the lowest level of competence. The system immediately indicates whether the answer is correct. About one third of the students use the quiz.

Each chapter of the lecture notes has a blank section at the end where students are supposed to write their personal *summary* of the chapter. This is to be done before, during and after the live plenary meeting. Sometimes I ask students to submit a photo of this section to me. Sometimes I ask them to compare their own keywords with those of their neighbour / exercise group.

Details of the live plenary phase

The elements described up to here are the flipped portion, that is, the delivery of the content. Up to this point, the students have received everything from me that I would teach in a conventional lecture. Everything else, i.e. the acquisition of the higher competences, would (have to) happen in a conventional course in the self-learning phase following the lecture, without guidance from the lecturer. In the concept presented here, it happens at least partly in 2x 90 minutes live, either in presence or via video conference due to the corona pandemic. However, I do not have to have achieved any goal by the end of the live session. Every question that arises can be discussed in detail. Everything is an add-on compared to a conventional lecture. Everything I would normally say and do is already said and done.

In the live session, I first ask the students to ask any *questions that are still open* within 5 minutes. I use Frag.jetzt to anonymise the questions. This seems important to me. We discuss the questions orally using illustrations from the script, sometimes wikipedia or textbooks. Typically we take 45 minutes in the first session of the week, and another 15 minutes in the second for open questions. I improvise here on the required topic, similar to the concept of '*just in time teaching*', even though my answers are shorter than the mini-lectures used there.

This answering of question is an exciting phase for me. The questions are written, sometimes too short and with little to too little context. It's not always easy to distinguish between a trivial question of understanding

and something deeper, also because I can't see which person asked the question. Especially with the more in-depth questions, my answers are then no longer polished for undergraduate students, but I use all the tools I have, demonstrating how the subject is applied professionally.

We use the remaining time to practice comprehension, application, synthesis and assessment to acquire the higher level skills. I base this on Eric Mazur's *ConceptTests*. I set a question, a task, which aims at higher competences. This is first answered individually by everyone using multiple choice (ABCD card or poll in the video conference). Ideally, there is a very broad distribution of answers. Then the working groups meet in their break-out room or groups of students sitting near each other are formed in presence. There they discuss the question and try to convince the group of their own answer. Finally, a vote is taken in the plenary again. Almost always, this is now the correct answer with 90% of the votes. This rhythm is similar to *think-pair-share* and all three elements are important. The first vote leads to a commitment of the students to one answer. The middle part practices comparing and judging. The last part gives feedback on whether everything worked. We clarify any questions that arise directly afterwards. Sometimes good reasons can be found for a supposedly wrong answer.

Not all questions are suitable for a multiple-choice procedure. Sometimes I have to leave out the first 'commitment' phase or replace it with 'think for yourself'. Sometimes the result is a drawing that all working groups make at the same time in plenary using the whiteboard function after the discussion. Sometimes short texts are created in the etherpad of the elearning server (also in presence). Sometimes we use the 'mutual assessment' function of the elearning server.

At the end of the second session I collect a kind of *one minute paper*. The assignment is 'Formulate a question that could be used in an oral exam to find out if someone has understood today's topic'. One aim is to reflect on the content of the week and its key points. The other aim is to collect questions for a 'review' session the day before the trial exam. I post the collected questions on the elearning system, which is particularly easy if they are also submitted there.

Details about the exercises

At the beginning of the semester we formed exercise groups of about 6 students each. Requests for dates were taken into account, but otherwise the groups were put together randomly. This way, the abilities within the group are more inhomogeneous, but the groups as a whole are more similar. My aim is to enable the groups to solve as many questions and problems as possible within the group.

The exercise sheets consist of about four tasks per week, most of which I have taken from the exercise pool that exists at our faculty. I have also developed new tasks, and slightly adapted the existing ones, to align the tasks more closely with the defined goals of the chapters. I want to achieve that each person, either in plenary or in the exercise group, has already done what I have asked them to do as an objective. It is not necessary that he or she has done this independently and without help, but at least has done it

him- or herself.

The students work on the tasks during the exercise group session in a kind of learning centre. I made sure that they also worked on the tasks before and after, alone or in the group. According to the survey, this is what happened. Handing in the exercises is voluntary. Watching the solution videos, however, is linked to this. Effectively, every group handed in every task.

Trial exam

Since all the content has already been taught before the live session, on the one hand there is no time pressure in the design of the live session. This can also be used for elements for which there is otherwise no time. For another, there is no need to link the content to the time it takes to write it on the board. In winter 20/21, for example, the content of what should have been a 15-week winter semester fits into a corona semester of 13 weeks. In winter 21/22, we used two live sessions to review basic concepts from the first year of the course and incorporate them into the context of this course.

Together, this made it possible to write three *trial exams* in the semester. In the exam, I look for competencies beyond pure knowledge. The lecture notes and all the student's own notes may therefore be used. The trial exams serve to accustom students to this format and to convince them of the success of their learning. In previous years, I was convinced that the students had achieved my goals, but they did not believe this. In the trial exam, everyone first works on tasks very similar to exam tasks on their own within 30 minutes and posts the solution in the elearning system in the activity 'Mutual Assessment'. Afterwards, the working groups meet in the breakout rooms and create a joint solution in another 30 minutes, which is again submitted via elearning. We then discuss any open questions. I actually only look at the group solutions. The individual solutions are automatically drawn among the participants and assessed by a total of 3 fellow students. In this way, everyone gets feedback on their own solution and abilities without me having to correct all the work. I take a random look at the feedback, which is almost always adequate.

Compulsory or voluntary?

As in winter 21/22, there are very few compulsory elements: a exercise assignment must be handed in by Thursday night so that you can watch the solution video for 7 days from Friday. Everything else is voluntary. According to the elearning statistics, almost all participants regularly undertook some kind of activity on the server. At the end of the week, almost all of them have watched the lecture videos. Whether this is also the case before the live session is not entirely clear to me. The statistics of the multimedia server seem to be time-delayed. Not all students give the online quiz. For all figures, it should be noted that several students may be sitting together in front of one computer. Activities such as 'formulate a question' are done to a greater extent if time is allocated / elapses for this in the live session than if posted

for after the session.

More coercion in the form of hard exam approval (50% of all assignments) or soft bonus points for assignments produces greater participation but produces more stress on both the student and lecturer side. Currently, I find it helpful to think that no activity would have happened in a conventional blackboard lecture, and see the extra part as positive rather than the missing part as negative.

Feedback

I typically conduct an anonymous lecture survey after about a third of the semester to optimise the process. As a consequence, I have, for example, made the solution videos visible for longer in this run.

The time required of the students is approximately 12 ± 2 hours per week. With 8 credit points, the nominal time budget is 14 hours per week plus 30 hours of exam preparation. The course thus successfully structures the students' self-study time.

The comments in the evaluation at the end of the semester are very positive (translated by ML)

- "The concept of working on the tasks together in the exercise is extremely good and the best exercise format."
- "The prof. somehow managed to create an atmosphere where you don't feel stupid (of course, you always feel kind of stupid, but it probably doesn't get much better than that)."
- "I find the whole 'flipped classroom' principle extremely good. The dicing of the work groups for the exercise sheets did scare me a little at first because it forces you to work with people you don't know, but it was really good for learning. This course took more time than other courses, but I finally have the feeling that I have understood something, which is otherwise not very much. So thank you :)"
- "The concept of preparing the lecture independently and then discussing the really important questions in plenary has, in my opinion, achieved its goal. Thanks to the group discussions, the question and answer sessions and the quizzes, in combination with the exercises that were well coordinated with the lecture, I always had the feeling at the end of the week that I had understood the topic well. The restriction of the content to the essentials and the concept of 'one topic per week' certainly contributed to this. Overall, I can say that I 'learned a lot of physics' in this course, i.e. I (better) understood many concepts beyond molecular and solid state physics."
- "I was initially very sceptical about the unusual format of the lecture with independent preparation and plenary. However, my opinion changed in this respect. The preparation was feasible due to the videos, in which the material was well explained, and the plenary sessions contributed to an astonishingly deep consolidation of the material. Moreover, suggestions for improvement were asked for and often taken into account."