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Student activation in theoretical physics lectures

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Summary. For theoretical courses, such as in physics or mathematics, it continues to often be common, to present lecture material in a blackboard-type format. This study addresses the question, if students of such courses might perceive this teaching style outdated, as many other presentation styles are possible. To this end, it was addressed, whether students of theoretical physics would prefer more student activation, that is, direct student participation in lectures. They were also asked to describe, in how far they would benefit from pre-recorded lectures, available before the actual class date, or from other forms of presentation, such as slide show performances. The results obtained were quite clear: for the type of lecture in question, 27 respondents mostly found that (i) blackboard presentations were the preferred teaching style; (ii) moderate student activation is useful in internalizing the teaching material; and (iii) replacing lectures by additional exercises, yielding more student activity would not be advisable, even if lectures were pre-recorded and available through the web.

Introduction

Evidence supports, that implementing changes in physics curricula, e.g., in terms of more research-focused teaching, is cumbersome (Dancy et al., 2010). The challenge of such implementation was found to be rooted in multiple factors, such as situational obstacles. A well-recognized teaching modification, which the majority of instructors in physics are reported to be aware of (Dancy et al., 2010), is peer instruction (Crouch et al., 2001).

Peer instruction aims to depart from classical teaching in physics courses, by allowed for more interaction between peers (student-student) as well as student-instructor. A key element of peer instruction is, that *all* students in the classroom should become engaged in the questions posed, and try to arrive at a conclusion *together* with their peers. Peer instruction has been shown to yield positive outcomes in student learning, when compared to more traditional teaching styles, for a variety of classroom settings (Crouch et al., 2001). In times, when a vast array of media is available for teaching, such as web-based interaction (Dey et al., 2009), traditional teaching styles in physics should be under scrutiny. Dey et al. (2009) mentions, that the use of multiple forms of media can allow for stimulation of various sensory input, e.g. words combined with pictures work better than using one of these alone. In their study, based on a specific experimental setting for undergraduate students, they found that recorded video presentations could be considered an alternative to "live" classroom presentations. They however also mention, that "live" lecturers might come across as more convincing, and that students were found to spend more time looking at the instructor in live lectures. Conversely, Kiesler and Sproull (1997) found that humans were more likely to interact with agents that had a human face, as opposed to a cartoon. Similarly, Lester et al. (1997) coined "the persona effect", by which learners preferred interactions with a "live-like character". An important point raised by Dey et al. (2009) is that students, who watched online presentations, in contrast to live lectures, were not motivated to take notes during the online presentation. Also this point will be addressed in the current study.

In this work, the key problem addressed is, whether, by which means, and to which extent, a lecture series in theoretical physics should be enhanced by student participation and varied forms of presentation. It is quite common in traditional theoretical physics lectures, to carry out most lectures as blackboard presentations, where mathematical derivations are written out explicitly by the instructor, and students often simply copy these notes down. Student participation often is seen as optional or perhaps even unnecessary, but can be encouraged by some instructors. It must be noted that, at many universities, the lecture may be supplemented by student exercise sessions, where the focus is on the students' performance in solving problems.

The particular course "Complex Physics", used here as an example, is a theoretical lecture series, geared towards MSc students in physics, but also allows students from other disciplines to participate. This year (Fall, 2018), the course was, for the first time, offered as a general degree course, that is, all students within the "general physics" study line were required to take this course. In previous years, the course was run under the title "Special Topics in Complex Systems", making it an elective.

With the new position in the course curriculum, Complex Physics received more students and posed a challenge of greater diversity in student level to the course to the course instructors (Prof. Kim Sneppen and myself). Adding student activation to the course lectures, mostly by interactive quizzes during the lectures, and more interaction during exercise sessions.

Context of the study - Course description of "Complex Physics"

Course style and role

This is a graduate course offered by the section *Biocomplexity* of the Niels Bohr Institute, University of Copenhagen. In recent years, approximately 20 to 30 students signed up for this course, and most of them participated in, and successfully completed, the exam. This year, a far larger number of 46 students have registered for the course.

To give some background, the *Biocomplexity* section is, roughly speaking, a disciplinary combination of statistical physics, biology and the geosciences. Most employees within *Biocomplexity* are theoretical physicists with interests in interdisciplinary work, especially in evolution and geophysics. The course "Complex Physics", is now, for the first time since its existence as "Special topics in complex systems", part of the standard curriculum for Master's level physics students at Copenhagen University. This explains also the larger number of students who have registered for the course this year.

Course organization

The course consists of two lectures (90 minutes and 45 minutes) and corresponding exercise sessions (90 minutes each). There are two class meetings per week, on Tuesdays and Thursdays. Currently, lectures are almost entirely "teacher-first" type lectures, carried out as black board derivations of relevant mathematical foundations for the different topics. Exercises, conversely, are almost entirely "student-first" meetings, where students solve homework assignments within small groups or on their own – as they prefer. The instructors are present to help discuss obstacles.

Range of topics covered

According to the course description, the topics covered are: Percolation, Networks, Phase transitions, critical phenomena, Monte Carlo simulations, interfaces, agent-based models, self organization, scale free phenomena, game theory, econophysics and models of social systems. Traditionally, the course also offered fluid dynamics and turbulence as a part of the standard curriculum. This additional focus had already been abandoned in recent years, partially because other courses at Niels Bohr Institute offered such aspects, partially because the range of topics within this course was already perceived as far too large (course website: https://kurser.ku.dk/course/nfyk 18005u/2018-2019).

Intended Learning Outcomes

According to the course description, which is now fixed for Block 1, taught in Autumn of 2018, the intended learning outcomes are, that, ***regarding skills***, at the conclusion of the course students will be able to implement simple quantitative models on a computer. The aim is to learn how to rephrase a complex phenomenon into a mathematical equation or a computer algorithm.

In terms of knowledge, the student is expected to gain basic knowledge on contemporary research in complex systems. This includes the ability to use fundamental concepts from statistical mechanics, non-linear dynamics, time series analysis, agent based models and self-organizing systems.

In terms of competences, students are expected to learn, how to describe and analyze non-linear systems in terms equations and algorithms. They are furthermore expected to develop computer models of systems with many interacting parts, including Monte-Carlo simulations, interfaces, networks, and cellular automata. Implement agents based models to describe self-organized dynamics of structures, for example within network theory and systems that behave similar across a wide range of scales.

Overarching objective

This course will provide the students with a competent background for further studies within complex system and biophysics, e.g. a M.Sc. project.

The course will provide the students with tools that have application in a range of fields within and beyond physics.

The **exam** is an oral exam of 30-minutes duration, typically taken several days after the final lecture, during which no further aids are allowed. The criteria for the exam assessment are mentioned to be the same as the "intended learning outcomes".

Description of intervention, aims and analysis data

Description

My intervention consists of allowing students to get active within the lecture, not only during exercises, and, additionally, allowing them to steer, to some extent, which detailed path the lecture will take. This was done, by implementing several elements of peer instruction. Short (1-3 minutes) exercises within groups of 2-3 students (usually neighbors in the classroom setting) were posed at irregular intervals during the lectures. Approximately three such exercises were presented to the students during a typical 90-minute lecture. During each exercise, when the time is elapsed, students are asked to propose solutions to the problems stated.

As a result of these exercises, I noticed, that in some cases the results of students exercises can lead the lecture into a somewhat different direction, which I then accepted and followed. It turned out, in some cases, to be a very fruitful "detour", as it allowed aspects to be covered that, mostly several of, the students were already contemplating. The challenge on the instructor side was, to finally gear the lecture back onto, or near, the path originally envisioned. However, by allowing for detours, the class became much more engaged and the lecture livelier.

Aims

The approach taken aims to put students in the center of the learning, as they are required to absorb the lecture material immediately by working with it. By taking up student questions within the lecture and diverging (somewhat) from the path intended, given students the feeling that they are actually in charge of where things go, rather than me, as a lecturer, guiding them through well-established material. Through the immediate feedback obtained from listening to the students' responses, the instructor may receive a much more "real time" signal on when to develop a side topic, when to repeat in other words, or sometimes, that it is reasonable to increase the pace of instruction (since all have reached the correct answer). Peer instruction, which could perhaps be seen as a form of inductive teaching, allows students to re-live the process a researcher goes through when developing an unknown theory. Students need to take steps they have not seen anyone take before them – hence, for them it is new and exciting. They may remember better, why it is important, if they were able to construct it themselves "from scratch". It will also be more satisfying to be able to develop a piece of theory without the teacher first doing it for them.

Analysis

Two types of evaluation were employed.

A. Qualitative: observations by three peer supervisors as well as one departmental supervisor, in order to evaluate the intervention.
B. Quantitative: Students were requested to fill in a survey, provided to them near the final lecture of the course. This survey was used to assess how students perceived the intervention. 27 out of 44 registered students responded to this survey.

Results

In the following, the results peer supervision and survey data are presented.

A. Peer and departmental observations: Peer observation was conducted by two associate professor, one from computer science (A), the other from forensic anthropology (B).
   Comments by A: getting more students to participate in questions, perhaps using more exercises, less questions (the particular lecture attended by A had a stronger focus on open class discussion, with fewer individual exercises, this format should perhaps be improved).
   Comments by B: some more clarity with student activation could be helpful, some students were not taking part in the activations, others were working on their own (which may not be considered a problem, as some prefer to work on their own).
   Departmental observation by two colleagues.

B. Survey results: After completion of my lectures, I asked the students to complete an online survey, containing both general questions, regarding the students' satisfaction with the lecture and exercise sessions, as well as specific questions, regarding the intervention. Out of the 44 students total, 27 responded to the questionnaire. Given that not all students were always present and not all students attempted the exam, this is a reasonable turnout for the questionnaire, and represents the class average relatively well.

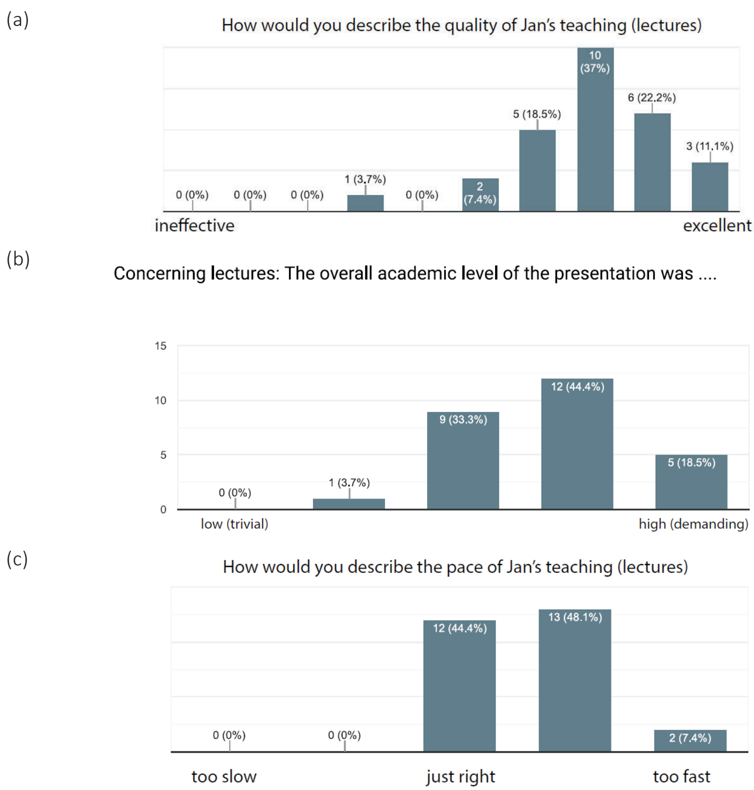
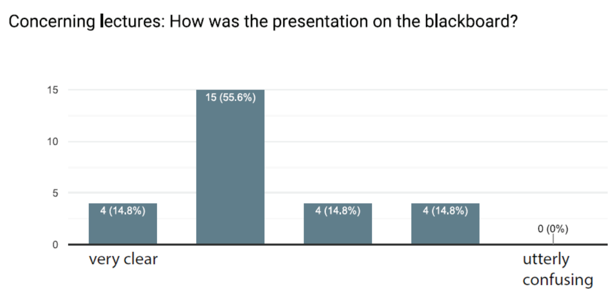


Fig. 5.1. a, Overall teaching quality, b, academic level of the course, and c, pace at which material was developed during lectures.

General course assessment

Figure 5.1a shows, that the quality of teaching was considered high, and only one student found the quality to be somewhat low. Almost all students were satisfied or very satisfied with the quality of teaching. When asked about the academic level of the presentation (figure 5.1b), the response was similarly positive, with most students finding the level high and nobody finding it low, i.e. trivial. Hence, the course difficulty and presentation appears to be acceptable for the class “Complex Physics”. To assess, whether teaching was overall too fast, students were asked to give their perception on pace (figure 5.1c). The response indicates that the pace was perhaps somewhat high, but not overly so. It could be argued that, at least at the graduate level, a somewhat too high level is preferable to an overall too low level of presentation, as long as weaker students are not overwhelmed with the pace.

(a)



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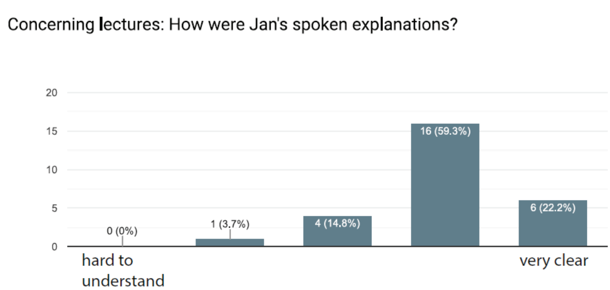

(c)

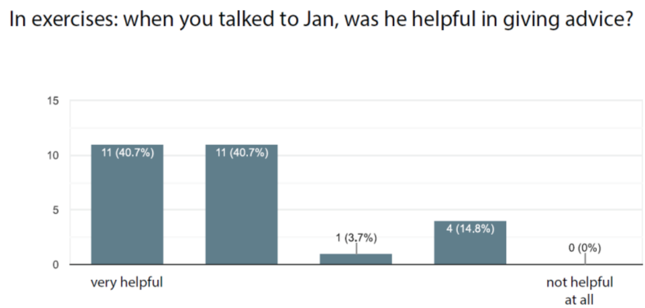

Fig. 5.2. Blackboard presentation, spoken explanations, and helpfulness in giving advice during exercises.

As I exclusively used blackboard presentations during the lectures, and an interest in the present study was to assess, whether modifications to such traditional blackboard style should be considered in this type of theoretical physics lecture, students were encouraged to describe their take on the quality of the blackboard presentation (figure 5.2a). The overall result is, that the presentation was generally considered quite clear (most students gave the second best grade). Similarly, an aim was to assess, how satisfied students were with the clarity of spoken explanations during the lectures, with satisfaction levels quite high (figure 5.2b). Exercise sessions consisted of student group or individual work (based on preference), with occasional intervention by either myself or the teaching assistant. Exercise sessions involved very little "frontal" presentation, most work was done by students on paper or using their laptop computers. Figure 5.2c shows, that, in exercise sessions, the satisfaction with the advice given by the instructors was reasonably high, with only few students less satisfied. Their partial lack of satisfaction during the exercises may be related to the lack of staff (only two instructors for 44 students), hence, not all students could receive help at the same level at all times, depending on their seating in the lecture hall, on their ambition to get the instructors' attention, and on the level of preparation for the exercise sessions. Further improvements could involve, that concluding summary presentations of the assignments could be given at the end of each exercise session. This would however cut down on the active group work that students were able to carry out.

Assessment of intervention

The aim of this study was twofold: to assess the merit of increased student activation in theoretical physics lectures, which were entirely blackboard based; to assess, whether the classical format of blackboard lectures should be reconsidered in the setting of theoretical physics. Student activations were implemented in terms of short quizzes or exercises, which were placed at irregular intervals during the lecture, with approximately three such exercises during a typical 90-minute lecture. The general objective of the intervention was, to invite students to work through short exercises alone or in small groups of two to three students (usually neighbors in class), to recapitulate the course material in a brief way, to strengthen the understanding of the blackboard notes, and to provoke questions and feedback. This intervention gave me immediate feedback on students' progress during the lecture, and occasionally allowed me to repeat crucial elements in a different way, so that more of the students were able to follow the subsequent material.

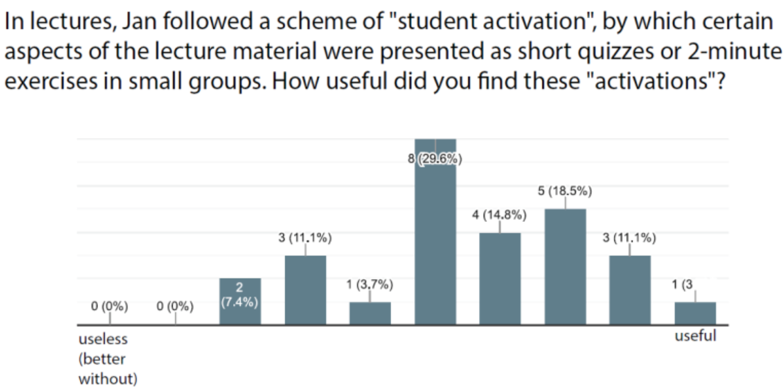

Fig. 5.3. Usefulness of student activation in lectures.

To more quantitatively assess the merit of this intervention, students were asked, whether they found student activation useful (figure 5.3). The majority of respondents replied, that these activations were useful, however, this was not experienced in an overwhelming way (the average assessment only slightly tends to the side “useful”, whereas approximately 20% of respondents tended towards “useless” and 30% had a mixed impression.

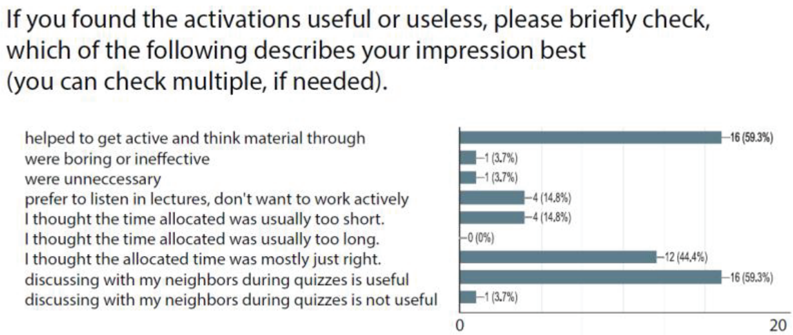

Fig. 5.4. Advantages of student activation.

To further differentiate the students’ perception, students were asked for specific reasons, why such activations might be considered useful or not (figure 5.4). More than half of the respondents (16/27) found that activations aided in re-thinking the material – which was the intention I had when giving such assignment. Equally many found, that discussing the exercises with their neighbors was useful. When asked about the time allocated to these exercises, most of those responding to this sub-question, found the time appropriate, while some found it too short, and none found it too long. I would hence advise in allocating somewhat more time to these exercises, since the risk of boring students appears low (while that of exposing them to stress seems somewhat higher).

Notably, some (15%) of students in fact prefer to work in a more passive way during lectures. Not all students find activations equally important. However, the general perception is, that some activation is beneficial.

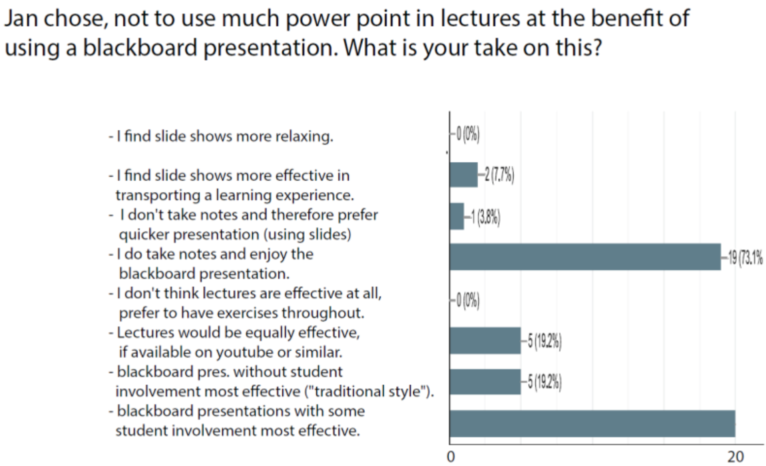

Fig. 5.5. Blackboard presentation vs other types of presentation media.

Since my lectures were entirely blackboard focused, I was wondering, whether students missed other types of presentation. For the type of lecture given, a slide based presentation style could, in principle, have been possible. Therefore, students were asked to contrast my presentation style to one involving either: slides (e.g., power point), or pre-recorded lectures (e.g., made available online), to allow the lecture time to be replaced by more exercises. Students were allowed to give multiple answers, as they pleased (figure 5.5).

The results on these questions were quite clear: Almost three out of four students preferred the blackboard presentation, stating that they prefer to take notes and like to copy material down from the blackboard. In my interpretation, this is difficult, or not satisfying, in the case of power point presentations, where the pace is generally much higher and material is therefore not copied down by the audience. Furthermore, I believe that the act of copying from the blackboard onto paper gives a stronger identification with the class material.

Regarding the option of pre-recorded lectures, available on the web, the results are clear. Only few students found this to be a reasonable alternative to “live” lectures in the classroom.

Regarding student activation, the results also left little doubt: Most students were in favor of some student involvement. Few, but not negligibly few (20%), of the students, however, preferred traditional lectures without any student involvement.

Discussion and Conclusion

Modern technology allows many forms of communication within classrooms or lecture halls. Theoretical physics lectures, which traditionally place strong emphasis on the development of derivations on the blackboard, make little use of this array of opportunities. The present work has queried, whether (a) the use of a wider range of presentation media would be useful to the students; and (b) whether stronger student activation would be advantageous.

The outcome obtained regarding (a) is overwhelmingly clear: most students queried are content with a blackboard-type presentation style and strongly oppose the notion of watching pre-recorded lectures as a video presentation. They are similarly opposed to slide-show style presentations in replacement for blackboard lectures. The main reason given for this choice is, that students enjoy copying material down to their notebooks during lecture – an activity which appears to be facilitated by the blackboard presentation.

The outcome obtained regarding (b) is somewhat more varied: many students do advocate some form of student activation, which they find to give them opportunities of absorbing the material more directly. However, several students were content without activations, as they prefer to simply follow the lecture. Few students were in favor of even stronger student activation, than the one implemented in this course (approximately 3x2 minutes during a 90-minute lecture). Overall, it should however be cautioned, that students may require a period of adjustment to a new teaching method, before the learning outcome improves (Sadler, 1998). Furthermore, the current study is limited in scope, as it only assesses the students' perception of the different teaching formats, while the study does not assess the actual effectiveness of the measures taken.

It should be emphasized here, that the majority of theoretical lectures in physics are supplemented by exercise sessions, where students are confronted with explicit problems they are expected to solve alone or often within groups of peers, under the supervision of one or several instructors/teaching assistants. That said, the blackboard format of delivering lectures appears to be especially characteristic of quantitative, and strongly derivation-based, lectures in theoretical physics or mathematics. Formats in other disciplines appear to vary widely, with slide show presentations constituting the more common presentation format. I can here only speculate, that ensuring a strong logical thread between different steps in a mathematical derivation can best be achieved by the student writing down (copying) the derivation. This very act of activating "a writing process" may be the most basic form of identifying and activating a learning process in students. Writing was reported as a means of forming structured and coherent knowledge (Rivard et al., 2000). This realization may also explain, why only a subset of students in fact is in favor of additional student activations in class, while some would even prefer fewer. Most students do enjoy the freedom to interrupt the instructor, to clarify questions.

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