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Rethinking Problem Classes in Physics

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Introduction

Problem classes are a very common teaching method in physics and other science courses. In this report I describe the problem classes as they are implemented in my own teaching; the difficulties I have come across; and a proposal for how ideas from problem-based learning may help to overcome some of these difficulties.

The course that I am currently teaching[1] involves weekly problem classes, in which the students and I work through the solutions to a set of mathematical exercises that were assigned to them in the week prior. The students do not have to hand in their solutions, but they are expected to be able to present their attempts and discuss their thought processes in class. In my experience, in these types of problem classes it can be difficult to successfully engage with the students, who often display a general lack of enthusiasm and a reluctance to contribute. Therefore although the classes are intended to be student-lead, more often than not they are instructor-lead, as I end up spending most of the time demonstrating at the blackboard. In this report I discuss how ideas from problem-based learning may help in creating problem classes that are more inspiring, more stimulating, and which ultimately improve student learning.

[1] The course material has been inherited from the previous course responsible.

Course Background

The course is called *Particle Detectors and Accelerators* (Course Description, 2019). It is a master's degree course and is part of the University of Copenhagen's MSc Programme in Physics. The course is considered to be a prerequisite for master's or PhD projects in the field of experimental particle physics, and is recommended for students specialising in other fields related to subatomic particles, such as X-ray physics, neutron physics, and medical physics. The purpose of the course is to teach how particle accelerators and particle detectors operate in modern physics experiments, and how experimental is analysed.

The course is comprised of lectures, problem classes and lab classes and each course week is typically split into three half-day sessions. The first session involves a lecture, followed by a problem class, where we work through the solutions to a set of mathematical exercises related to the material covered in the previous week's lecture. The second and third sessions involve lab classes, where the students have a hands-on experience of operating various particle detectors, processing signals, and analysing data. The course assessment has two components: 80% of the assessment is based on an oral examination, in which each student is randomly assigned a real-life particle physics experiment and is asked to discuss the idea and concepts behind it; and the remaining 20% is based on a continuous assessment of the students in the lab classes and problem classes.

Difficulties Observed

After teaching this course for the first time in 2019, I noticed that the students often showed a general lack of enthusiasm for the problem classes, in comparison to the lectures and lab classes. It was therefore not so surprising to find out that the students themselves did not find the problem classes particularly helpful to their learning, as indicated by the results of an anonymous, post-course questionnaire shown in Figure 17.1.

Furthermore, in the final section of the questionnaire, where students were invited to comment on any particular aspect of the course, they provided the following statements:

- *'The exercises that we do in class are nice but some exercises are just like "insert number" and is not clear why we are doing this'.*

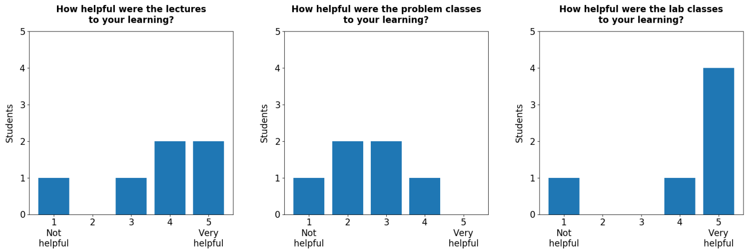

Fig. 17.1. A subset of the results from an anomymous, post-course questionnaire sent to the seven students who participated in the course in 2019. The questions are in the form of Likert scales, in which the responses can range from 1 (Not helpful) to 5 (Very helpful).

- *'I think that we should do something more difficult and qualitative, to create a discussion between students'.*
- *'I think that we should have extra activities during the course, not only the exam and reports... Maybe simulations or other activities'.*

From these comments it would seem that the students do not see much value in the problem classes in their current form, but they do still have an appetite for challenging activities that promote class discussion.

As well as receiving feedback from students, I also invited a colleague (who has a special interest in teaching) and an academic from the local Department of Science Education to come and observe one of the problem classes. They pointed out that many of the exercises are rather structured - in the sense that there is one correct answer and a well defined recipe that students are expected to follow in order to get to get to that answer. These kinds of *closed* exercises may well be partly responsible for the difficulties in generating classroom discussions, since students may feel that if they don't know the answer then they have little to contribute to the discussion. In addtion, these closed exercises may lead students to focus primarily on getting the correct answers, thus encouraging them to take a surface-learning approach to the course material.

As a side note, given the apparent popularity of the lab classes, as shown in Figure 17.1, it could be argued that the problem classes should simply be replaced with more lab classes. However I would be rather reluctant to drop the problem classes entirely at this point, as I feel that some of the courses intended learning outcomes - most notably *to be able to create a new design, or evaluate an existing design of a particle detector or particle accelerator system for a given purpose, using analytical methods* - are best served by problem classes. The focus should therefore be on trying to improve the problem classes.

Proposal

Based on my understanding of the problem, as outlined in the previous section, my proposed solution is to move away from the traditional, end-of-chapter-style, closed exercises, in favour of a Problem-Based Learning (PBL) approach. PBL is a student-centred teaching method in which students investigate relevant, open-ended problems for which there is no single correct answer. Physicists generally think of problems as having only one correct solution, which can make it challenging to come up with student assignments that are relevant and insightful, whilst still being open in nature. Nevertheless, PBL is gradually becoming more prevalent in the physics departments of higher education institutions (Raine & Symons, 2012). In fact advocates of PBL have been actively encouraging its use, in physics specifically, through the publication of practical guides and case studies (Raine & Symons, 2005). They would argue that PBL supports critical thinking and promotes a deep, constructive approach to learning. The hope is that by taking a PBL approach, the open nature of problems will give the students the opportunity to be creative; to pursue their own ideas; and to bring vibrant discussions to the classroom.

My plan for the course in 2020 is to introduce new problem sets centred on computer simulations, as was suggested by one of the previous students. The use of simulations may prove to be a valuable tool in teaching, given that they can provide a visual representation of phenomena which is typically described in the form of written equations. The new problem sets would involve challenging the students to create simulations of various physical phenomena, and to use those simulations to perform virtual experiments. For example, they could be asked to simulate a particle passing through matter, and then investigate what happens when you change the particle's initial energy, angle of incidence, or the type of material. There would be no requirements on the level of complexity of the simulations; the students would be free to decide that for themselves. Moreover, the limitations of the simulations, with regards to how well they describe reality, would provide points for discussion. Each of the students would then present their findings in class, where they would be reviewed and discussed, and the new knowledge consolidated.

A typical feature of PBL is group work. It has been well documented that working collaboratively can have a positive impact on learning outcomes (Johnson et al., 1998a, 1998b; Springer et al., 1999), and so students will be strongly encouraged to work together in small groups. This not only provides them with an opportunity to give and receive feedback to each other, it also allows the group as a whole to cover more lines of investigation and therefore delve deeper into the problem.

Outlook

The one obvious concern with regards to the proposed changes is that the students may not be sufficiently literate in computer programming to participate in a meaningful way. I am fairly confident that this will not be the case, since students are exposed to computer programming in a number of courses within the MSc Physics programme. In the unlikely event that the issue does arise, pairing the most experienced computer programmer with the least experienced would be the most obvious solution. Another potential concern relates to the fact that the students will now be working in groups, which had not been the case in 2019. The learning outcomes for each group will be dependent upon the ability of the students to work together. Again, I don't forsee any major issues in this regards, however it would be worthwhile to establish, in advance, a framework describing how collaboration must take place.

The main challenge will most likely be in evaluating the impact of the proposed changes on the students learning, since there is no clear, definitive means by which this can be measured. Determining whether or not the proposed changes could be considered successful, will be based upon the combination of my own observations during the problem classes; the examination results; and of course the opinions of the students, collected via an anonymous post-course questionnaire.

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