PROJECT-BASED COOPERATIVE LEARNING IN ACCELERATOR SCIENCE AND TECHNOLOGY EDUCATION

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Abstract

Project-based learning uses a project to enable students to learn practical knowledge, often supplemented with some introductory lectures. (PrBL) has been employed at the Cockcroft Institute as part of their postgraduate programme in particle accelerator physics and engineering. 40 students have taken part in two schools. The students are made to work in groups to enable cooperative learning to further enhance learning. The outcome for these students is compared to a similar number of students taking conventional lecture based education and is shown to enhance the ability to apply knowledge.

INTRODUCTION

The next generation of particle accelerators will require the training of greater numbers of specialist accelerator physicists and engineers [1]. These physicists and engineers should have a broad understanding of accelerator physics as well as the technology used in particle accelerators as well as a specialist in some area of accelerator science and technology.

Since 2007 the Cockcroft Institute has graduated 61 PhD students in accelerator science and technology. The Institute runs a two year postgraduate lecture programme. However the schedule of only two lectures a week meant that the basic course is only completed in December, 3 months after the students start their research project. In order to have a faster start in 2013 and again in 2015 we decided to run an intensive two week "school" to replace the basic course, followed by our standard advanced programme running one day a week. We decided to investigate the use of problem based learning to simulate the way accelerator science tends to work in practice.

The aim of the education programme is to focus on the accelerator science and technology allowing us to have a deep and broad coverage in this specialist topic. The lectures are free and open to students outside of Cockcroft Institute via a webpage [2]

PROJECT BASED LEARNING AS AN APPROACH

A similar technique of Problem based learning (PBL) was first implemented in 1969 at McMaster University in Canada for the study of medicine, where students were presented to patients and their problems [3]. The course emphasised the use self-study and was supplemented with small group discussions and laboratories. In PBL the emphasis is on knowledge acquisition through problem solving. PBL is well suited to medical education where encyclopaedic knowledge is required and the order topics are learned is not a major issue. However PBL presents two issues when applied to accelerator science and technology. Accelerator science learning is hierarchical, with often complex interrelated subjects, and the order in which it would make sense to learn the required knowledge is not always the same as the order in which topics are met in a problem, it can also lead to some topics being overlooked. For example the design of a 3rd generation light source starts with radiation production in dipoles and undulators, however this first requires some knowledge of accelerator physics and magnets and later will need some iteration including requirements for vacuum and RF as well as refining the optics models once the RF frequency is known.

We show in this article that these issues can be addressed when PBL is used in conjunction with lecture materials and the problems closely resemble engineering projects. Here projects tend to be longer than problems, have a defined start and finish, and can be multidisciplinary. As such this type of learning is often called project-based learning. This type of course has been introduced at Eindhoven [4] in the teaching of mechanical engineering in 1994. In this article the projects are performed as groups to develop co-operative learning. Co-operative learning is a method of encouraging students to learn from each other rather than from the teacher alone [5], and is often included in PBL environments.

CI PARTICLE ACCELERATOR SCHOOL (CIPAS)

It was decided to utilised project-based learning to reinforce the lectures at the Cockcroft Institute based on evidence from the literature previously discussed. It was felt that it would be beneficial to supplement this with lectures hence project-based learning was chosen. It was decided to create a two week school comprising of lectures in the mornings and a design exercise in the afternoon. In order to cover all the required elements for particle accelerators the design exercise was based on a 3rd generation light source. The design exercise is split in six tutor-guided exercises:

- Accelerator, dipole and undulator specification
- Lattice design (in MAD)
- RF systems design (in CST)
- Dipole and Quadrupole magnet design (in OPERA)
- Diagnostics requirement and locations
- Specify vacuum pumps, apertures and materials.

As with the Eindhoven method the tutors can give some direction to the students but it is ultimately up to the students which direction they take. The students also have a dedicated section for revisiting past exercises to revise designs based on new information from later exercises. In order to benefit from co-operative learning, all the students are split into groups of five to design the light source. The specification for each group is slightly different leading to different beam energies and technology choices. In keeping with the Cockcroft aims of providing a broad application all students in each team must take part in all design elements and students are not allowed to focus on their own area of specialisation. The total number of hours spent on the project is around 30 hours.

At the end of the school the students are given a lecture on accelerator physics in real life covering the experience of practicing accelerator operation staff. The students then present their accelerator design to the institute staff, and this is followed by an external seminar on a real 3rd generation light source. Once piece of anecdotal evidence to the success of the school is that the students ask several relevant questions at the end of the talk showing their increased understanding of accelerators and the students new found enthusiasm for the subject.

This is not the first use of project-based learning in accelerator science as a similar approach is used at the end of the lecture program at the John Adams Institute [6]. However a few key differences should be noted in our case as the design projects run in parallel to the lectures, and all students take part in all parts of the exercise and students are not allowed to specialise. This leads to a broad learning for all students and a greater emphasis on co-operative learning.

LECTURES AND THE ACCELERATOR DESIGN EXERCISE

The starting point for the design exercise is the specification of the undulators and dipoles based on the photon specifications given to the students. This gives the students the energy, current and size of the particle accelerator. This part of the exercise follows from lectures on synchrotron radiation, however before this can be covered the students must first learn basic accelerator physics so the first day focusses mostly on lectures. The first lectures focus on the motion of charged particles in magnetic fields covering linear optics, as well as covering the use of dipoles for bending beams and quadrupoles for focussing them as well as sextupoles for correcting for energy spread in the beam. The students then learn how to calculate the photon spectrum and brightness generated by bending charged particles. Once the energy and current is known the students then move to the 2nd part of the design exercise which is determining the position and field strengths of the dipoles, quadrupoles and sextupoles. These are simulated in the beam dynamics code MAD [7] to minimise the beam size.

The next part of the design exercise was to design the radio frequency (RF) system, used to accelerate the particles. The lectures covered the basics of RF cavities, couplers, cavity filling, RF power sources, higher order modes, wakefields and superconducting RF. All four lectures were aimed at giving the students the skills to develop a strawman design of an RF system in the design exercise including the RF frequency, the number of cavities, the operating voltage, the RF power sources and the decision to use normal or superconducting systems. This design was then solidified after performing a design of the cavity geometry using the electromagnetic code, CST Microwave Studio [8], including the required aperture to minimise wakefields.

The OPERA finite element code from Vector Fields is used to design the magnets themselves given the field strengths chosen earlier, and they can then apply the techniques learned in the lecture on magnets to design the cross-section of a dipole magnet in 2D. The students can make an informed choice about the geometry of the magnet, decide which symmetries can be applied to the model, and calculate the current density required to generate the correct field level. They can then use this information to build a simple 2D model of a dipole, verify that it generates the correct field, and modify the geometry to improve the field quality. Similarly for the quadrupoles, the students will have the numbers for focussing strengths from their lattice simulations and can follow the same procedure.

The students also had to consider the diagnostics required to measure beam properties and how the accelerator behaves. In the tutorial participants were asked to include (what they thought) the most important diagnostics in their design studies, propose adequate locations and also establish a rough costs estimate. Finally the students had to specify the vacuum system, including calculating the required pressure and selecting an appropriate pump technology and working out how many were required and where they were needed.

FEEDBACK FROM STUDENTS ON CIPAS

In order to assess the long term impact of the school all the students who completed the school were interviewed one year later to see how useful they found the design exercise in hindsight. Seven questions were asked in the interview and we present the answers to three of them here:

Was the school useful to you?

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All 14 students questioned felt the school was useful. They felt the course gave a good overview of accelerator science and technology, covering a breadth of topics in the field.

How did the design exercise compare to traditional lectures/tutorials as a vehicle for learning?

Overall most students said that the project aided their learning, albeit to different degrees. From the student feedback it is clear that different students learn in different ways. Some students said the project based learning was much easier for them than traditional lectures and it led to better understanding and better retention of learning, other students said they learned better from the lectures. This suggests that project based learning, where the project is backed with traditional lectures is better in this case than problem based learning where the student learns entirely from the problem. Some students had specifically mentioned that they did not understand some of the lectures until they did the design exercise "The beam dynamics lectures were frustrating but the design exercise part on this later made the understanding of beam dynamics easier." "Better, never truly understand the theory until you have used it". The student comments were best summed up by one student saying that the design exercise was a "good way of bringing everything together."

Other than the lectures on your own PhD topic area, have you used any of the other lecture subjects during your PhD? Was the breath useful?

Given that most accelerator based PhD students design a device or technique that they apply to a real accelerator at the end of the PhD, almost all students were certain that they would need to apply the accelerator science, diagnostics and vacuum parts of the course at the end of their PhD. Some students had already applied parts of the course as part of their PhD. In one case the student had changed their PhD topic since the course and said that the breadth of the course helped them in that transition.

Was the team work part of the course beneficial to the learning experience?

All the students felt the team work helped the learning process. The students comment that as they all have different educational backgrounds, the students have different levels of experience in particular areas. This means that the students who had relevant experience could help the other students. Students commented "some students had accelerator experience already and they helped others" and "Different UG backgrounds meant that everyone had something to add and we all helped each other".

ACCELERATOR ASSESSMENTS

After the first term the students undertake an assessment to focus learning and to assess the performance of both the student and the course. There are three assessments, beam dynamics, RF and magnets. The course work is a take-home assessment and the students have 1 month to complete each assessment. Assessments were given to the 2014 intake of students who did the standard programme and the 2015 intake who did the CIPAS in order to compare the student's grasp of the learning outcomes for each teaching method.

In the RF assessment students have to demonstrate design and comparison of linacs, calculation of cavity parameters, and demonstration of understanding. In 2014 the assessment was based on RF system design, this was felt to be too similar to the CIPAS project to be a good assessment of the students' abilities, hence in 2015 the questions were revised to probe understanding. Unfortunately as the questions were different each year it doesn't allow a direct comparison. However one question was kept the same in both years where the students were asked to calculate the impedance of a dipole mode in a cavity. This required the use of field equations with Panofsky Wenzel theorem to get the transverse voltage. An added difficulty was that one of the integral equations required didn't have an analytical solution so the students had to solve it numerically. In this question the average mark in the first year (2014) was 35%, while after the CIPAS (2015) the average mark was 46%, demonstrating that the CIPAS has likely led to an improvement in the students' ability to apply understanding rather than just design calculations although more data is required to ascertain if the method has led to this improvement.

The beam dynamics assessment was designed to test the two core skills of performing beam dynamics calculations and design in the real world. The first is tested by a demonstration of the grasp of theoretical concepts with a series of questions requiring thinking and calculation of physical quantities. The second was an exercise in lattice design, requiring a simple lattice to be developed and properties extracted using either a standard beam optics code or through the development of a custom code. The assessment was the same for both years. In the first year, the mean was 59.5%, with a standard deviation of 6.4% while in the 2nd year, after CIPAS this increased to 74% with a standard deviation of 5.5%.

In the magnet assessment the students had to apply Maxwell's equations to calculate the profiles of the magnets. The assessments for both years were very similar. The marks in 2014 was 59% but this increased to 66% for the 2015 intake of students, however the standard deviation was around 20% in both years. The standard deviation makes any conclusion on the increase of students' marks difficult to make.

CONCLUSION

Between 2013 and 2015 the Cockcroft ran a traditional lecture based programme in accelerator science and technology with and without a design-based learning exercise. Student feedback forms, interviews, verbal feedback, anecdotal and assessment evidence has been utilised to assess the effectiveness of the two methods. There is a clear trend from the evidence shown in this paper, including the assessment, interviews and feedback from students and anecdotal evidence, that the design exercise is a very effective method of teaching accelerator science and technology.

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