Reporting on experiments with research integration in teaching

Name
Kim Splittorff, Associate Prof, the Niels Bohr Institute, SCIENCE, KU *Co applicants: Prof Anders Sørensen (NBI, SCIENCE) and TT Assistant Prof Markus Ahlers (NBI, SCIENCE).*
Course Name
Quantum Mechanics 1 (course responsible Kim Splittorff) *https://kurser.ku.dk/course/nfyb10013u/2022-2023* *Quantum Mechanics 2 (course responsible Anders Sørensen)* *https://kurser.ku.dk/course/nfyb10010u/2022-2023* *Advanced Quantum Mechanics (course responsible Markus Ahlers)* *https://kurser.ku.dk/course/nfyk15003u/2022-2023*
Study Board
Study board for Physics, Chemistry and Nanoscience
Level and class size
Bachelor 2nd year, master's1st year. At BSc level approx. 100 students in two consecutive courses At MSc level approx 70 students
Description of the experiment
Until now learning quantum mechanics has been like training swimming on land, or learning mechanics without having a ball to throw. However this project has made it possible for students in 3 courses to set up and run highly controlled quantum experiments on the IBM Quantum Computers. The possibility to conduct such extremely delicate quantum experiments, allows the students to develop an intuition for quantum mechanics. *Student assessment: One of the 3 courses (Advanced Quantum Mechanics) has been completed and the students have given a positive assessment of the new quantum experiments and in addition have provided very constructive feedback. Furthermore we have gained good experience with the practical issues concerning the integration of the IBM Quantum computers into the courses, which we are already making use of now in the other two courses (Quantum Mechanics 1 and Quantum Mechanics 2).*
Outcome for the students

The hardest thing learn when it comes to quantum mechanics is the interplay between superpositions, entanglement and measurements. These are key learning objectives in all 3 courses mentioned above, as they form the very fundament of quantum mechanics. Not only has the project given the students a chance to make extremely controlled quantum experiments which helps them get a better feeling for superpositions, entanglement and measurements, they have also learned to operate the perhaps most advanced technology that mandkind has produced.

Outcome for the research

It is essential for the research in quantum technologies to have students which enters with an excellent understanding of quantum mechanics and of the possibilities which quantum technologies can offer. The project has in this way contributed to the many quantum research centers at the Niels Bohr Institute.

In addition for the Quantum Mechanics 2 course we are implementing a newly released feature in IBM's Quantum computers which has direct relevance for the research on how to build a quantum computer.

Interaction between teaching, research and exams

The experiments conducted by the students on IBM's quantum computers is in two of the 3 courses a direct part of the continued evaluation. In the Advanced Quantum Mechanics course this has been conducted smoothly. The students are currently working with experiments designed for the Quantum Mechanics 1 course.

Adapting of the experiment

The completed experiments has to a great extend been realised as originally planned, a few changes of technical nature has been made to adopt to the continued developments of IBM's quantum computers and the associated software which is used to controll the experiments. Continued adaptation will be needed to follow these developments, but the main line of the experiments can be used again.

Strengths and weaknesses

The most important strengths of the experiment is that it gives 1) the students a chance to develop an intuition for quantum mechanics through controlled experiments 2) that the students work directly with advanced technology used and developed in research.

As with all experiments which are controlled remotely (observations from satellites, remote observatories, large experimental research facilities such as CERN, ...) it would be great for the students also to have a direct hands on experience with a quantum computer. At the Niels Bohr Institute we are working on creating a quantum teaching laboratory where this is possible.

Experienced challenges

There is smaller a technical challenge with the availability of IBM's quantum computers, as one may have to wait a bit in line when conducting the experiments. But we have found ways to circumvent these issues.

The most important experience

The most important experience from this project has been the confirmation of the central role which experiments play in students role to learn a highly abstract subject such as quantum mechanics. It is fantastic to see how students suddenly grasp the indeterminate nature described by quantum mechanics when they see it directly in an experiment.

Will the experiment be conducted again?

The experiments conducted by the students on IBM's quantum computers is by now an integrated part of the two courses Advanced Quantum Mechanics and Quantum Mechanics 1. If the experiment we are conducting in the course Quantum Mechanics 2 is equally succesfull it will be conducted again in the years to come.