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Designing an effective experimental quantum science laboratory

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The test of all knowledge is experiment.

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RICHARD FEYNMAN

Introduction

The study of quantum physics and quantum information is booming, with research and career opportunities abounding in the field, both for physicists as well as biochemists, computer scientists, nanotechnologists, and engineers. Targeted training is therefore required in this field at the undergraduate level, however the non-intuitive nature of quantum physics can hinder deep learning and internalisation if only theoretical aspects are discussed. These topics require deep engagement, ideally in the form of laboratory exercises. The Niels Bohr Institute, while a premier institute in the field, lacks a unified quantum/condensed matter laboratory. Therefore, it has been difficult to provide students with hands-on experimental work in the lab concurrently as students are learning about the topic. During this project, therefore, I worked towards an actionable blueprint of an effective quantum laboratory, based on student reactions and evaluations of the current laboratory setup and a few targeted changes. I teach two laboratory courses, within which these ideas are tested: Primarily, (I) a mandatory Bachelor course in the Nanoscience program ("Nano 3") and secondarily, (II) an elective Master/PhD course in experimental condensed matter physics (Condensed Matter Experiments, or "CME"). During the project, a small quantum teaching lab was implemented based on various equipment and experiments existing from previous iterations of the two courses; I will relate how this was received, and how is on its way to forming the foundation of a state-of-the-art laboratory with external funding. Project findings included a resounding affirmation of the need for modern laboratory equipment that did not distract students from the actual experiment, and some positive benefits of tying assessment to the experimental labs and making it student-led. They also included some surprising findings about the importance of time management around scheduling experimental laboratories.

Course context and problem analysis

Theoretical context

Research into student understanding of quantum physics and quantum technology via experiment and physical laboratory-based teaching is an almost unexplored field, perhaps because the field itself is still in its ascendancy. Previous work focuses on computer-generated simulations, quizzes, and clicker-based activites, nevertheless finding that these improved learning outcomes (Krijtenburg-Lewerissa et al., 2017; Muller & Wiesner, 2002). Dzurak et al. (Dzurak et al., 2022), describe in great detail the development of a course for the quantum engineer, with a section for a laboratory component, but results are not yet explored. From my own practice, I have taught in a first-year physics laboratory course ("Undergraduate Preparatory Certificate course, Physics module, University College London website", n.d.) at University College London, UK for two years, where a major goal was to afford students unrestricted time to interact with and engage with the experimental setup. Additionally, lab work was also weighted into the final grade. Lastly, the goal of the experimental laboratory is only partly to facilitate understanding of the course topics; it is also paramount that students learn the scientific method, and are enculturated into the practice of scientific experimentation (Agustian, 2022), including collaboration, good record keeping, data analysis, research ethics, and reporting. The epistemic domain must also therefore be kept in mind when we design an effective quantum laboratory.

Course context

I teach and am coordinator for a course within the Nanoscience curriculum, named “Quantum Phenomena in Nanosystems”, commonly known as “Nano 3”. I first taught it in the spring of 2021, a year where this course with a strong laboratory component had to be held online (such that artificial lab-like exercises consisting mostly of data analysis were used), and again in the spring 2022, where it was in-person, with the interventions detailed in this project report. On another course, for Master/PhD students called “Condensed Matter Experiments” or “CME”, I have handled lab activities for two years now. In both cases, lab manuals and the content of the experiments themselves were created and handed down by me and my colleagues teaching the course in previous years, and my project interventions consist of the design of the quantum lab and not specific experiments: experimental apparatus, location, as well as assessment methods. Additionally, the end of the Covid-19 lockdowns during which experiments had been mostly halted, emphasized that a re-start of the NBI quantum teaching laboratories was now possible. Therefore these two courses served as testbeds for designing a future world-class teaching laboratory.

At the beginning of the project, I identified, via brainstorming, and discussion with TAs and co-teachers, a few critical problems which we felt de-motivated the laboratory components of the course and decreased student engagement with the laboratory exercises. These were:

- The location and physical environment of the experimental laboratory, which was sub-par.
- Constraints on experimental apparatus that meant students spent more time getting apparatus to work than in performing experiments, and were constrained in their experimental creativity and unable to gather data in interesting regimes.
- Disconnection between course material and laboratory exercises, and the perception that labs were an “extra” component that did not factor into assessment and were therefore not as important.

These crucial “pain points” were therefore tackled first, and are the basis of the interventions and results for this project. Insights gathered from the students about these three points fed into the basis of our first blueprint for an NBI quantum science teaching laboratory.

Project implementation

The first major intervention, of course, was restarting experimental labs after Covid-19 and bringing the experiments in-person instead of conducting online and artificial “virtual” experiments which often boiled down to data analysis. To give some context about the typical experiment (see Fig. 1), a typical activity is to take a sample showing some interesting property, connecting it via wires to some apparatus that can be cooled down (typically called a “cryostat”) and in our case, dipping it into a vat full of cold liquid (called a “cryogen”). This is followed by measurement of its electrical properties, such as the current flowing through it. Students can apply voltages, connect instruments, measure device properties, and analyse data.

The physical space

Previous studies have described the role of the teaching laboratory as a physical space that facilitates student enculturation into science as a field, peer-group interaction, and practicing collaboration (Agustian, 2022). Here, students are free to explore the domain and test the theory they have been taught without the influence and primacy of the lecturer. Especially for the counter-intuitive results some quantum theories predict, such a space where students can convince themselves of these results is important. Previous iterations of the CME course laboratory had taken place in the only space that was available, a small 2 by 4 meter room without ideal ventilation, operable windows, and where only one team (2 to 3 maximum) of students would fit (Fig. 1). This is obviously not an ideal space for interaction and based on TA input, we decided to prioritize optimizing the physical laboratory space. A new room was arranged (Fig. 1) and three PhD students (two of whom had taken CME, and were subsequently TAs for Nano 3) were involved in designing the physical space, organising and grouping the equipment, desks and chairs (as well as rewriting and updating laboratory manuals), leading to student involvement in the partition of the space and design of the laboratory. A room capable of hosting three to four student teams was chosen, with windows, much better ventilation, and space for a cryostat and multiple experiments. Previously, small room size meant that some equipment was put away in a cupboard, leading to students having to spend extra time in setting up their experimental station. The idea was to make the laboratory an appealing space to aid student exploration, so that they would not solely focus on rushing through the lab manual in isolation and leaving, but would want to try out different approaches and equipment.

The role of equipment

Bernhard et al. (Bernhard, 2018) come to the conclusion that "the role of experimental technologies in students' learning in labs should not be neglected". As described in the previous section, most of the explorations of quantum laboratory design have focused on online and computer gamification (Krijtenburg-Lewerissa et al., 2017), animated models and virtual experiences (Muller & Wiesner, 2002) such as operations on the IBM-Q quantum computer (I and others from the NBI (Warner, 2021) have led such experiences, which can be fruitful as well). During remote and in-person teaching of Nano 3, we found that virtual interaction with data was perceived vastly differently by the students than the actual physical experience of performing the experiment; indeed students from the previous year's online-only class during Covid-19 urged lecturers to bring back in-person labs for the next iteration. Bernhard also adds:

> The role of technologies is often neglected or taken for granted, and researchers focus instead on the concepts, ideas, and structures of labs. Researchers may also treat real physical labs as homogenous settings when comparing them with, for example, virtual labs...failing to exploit the full advantages of experimental technologies and labs for learning. The technology is a "cognitive tool".

The experimental apparatus is in a sense, a necessary intermediary for students to physically interact with the quantum world which cannot be perceived by their senses, and therefore it must be efficient and well-designed. It needs to be tactile, giving a hands-on experience, while also robust to failure and misoperation by inexperienced experimenters. As Dzurak et al. (Dzurak et al., 2022) put it, one needs to take a "fragile quantum experiment out of a research laboratory and put it in front of students such that it produces the desired results consistently, in a short time period, and in an ill-controlled environment." Several universities have developed hands-on practical teaching laboratories (though very few specifically in quantum science), and many of these teaching laboratories are based on an educational kits, from companies such as TeachSpin ("Teachspin instrumentation suite", n.d.), Qubitekk ("Qubitekk lab kit", n.d.) and others (these can be viewed as sophisticated pre-designed experiments, like a LEGO kit). However, a lot of these kits are restricted to room-temperature experiments (such as quantum optics demonstrations (Enrique, 2019; Muller & Wiesner, 2002)) and nanoscience and condensed matter physics topics require low temperatures and cryogenic operation.

Yet other universities rely on home-built teaching kits, put together by the professors or by the TAs, and this is the type of experimental setup the NBI has historically favoured. Since we felt that this kind of setup integrates research components and mirrors research methods of building experimental setups, we decided to keep this general ethos. The goal of this section of the project was to determine the role of equipment and to what extent it was a hindrance for our current laboratory. To this end, a short questionnaire was developed (Appendix A) and added to the student evaluations filled out at the end of the course for Nano 3. The hypothesis we had developed was that the main limitation to an efficient experimental setup was the fact that the laboratory lacked a stable cryostat where the temperature could be well-controlled and where a suitable magnetic field could be applied, and which did not constrain the experiments. However, we were also unsure if students would feel this as a large obstacle as it did work “more or less”. For example, other issues could have been more important to them, for example the lab manual being unclear, or coding and data-taking being too difficult. As the next intervention would be to petition the university and external funders for a large, stable (and expensive!) cryostat, we wanted to find out the importance of the role of equipment.

Assessment and practicalities

A third aspect of designing a laboratory is the human aspect; group work, time scheduling, and assessment. Students were assigned to work in groups of between two to four students; prior experience has shown that three students is a good number; two may be too few in case one student is unable to contribute much, while four results in a crowd around the experiment. However, in practice, this number was set purely by the size of the course (CME, eight students in groups of two and Nano 3, $\sim$30 students in groups of four) and the limitations of the physical space and equipment, and not by taking didactical concerns into account. This could be a worthy intervention in future, but was not explored for this project.

A second decision was to be made about the scheduling of laboratory exercises. In the lecturers’ previous experience at institutions abroad (USA, UK), laboratory exercises are organised outside lecture hours, at the students’ own convenience. The rationale behind this was to allow students flexibility as groups may naturally work at very different speeds when the activity is fully student-led, and due to the very nature of laboratory work where equipment may fail and the sample may fail to cooperate. We also wanted to facilitate unlimited exploration of the sample and the apparatus. Indeed, while it was found that some students (and definitely the TAs) appreciated this, it was wildly unpopular among many other students, who found that this led to too much time being spent on the course (detailed in the Results section).

Alignment and Assessment: Prior didactical projects at our institute found that an alignment between lectures and laboratory exercises can impact student exam results positively (Grove-Rasmussen, 2011) and adding student responsibility for some aspects of the course could be beneficial (Kuemmeth, 2019). This was also taken into account during the design of the restarted quantum laboratory. A two-pronged intervention was therefore made; first, both labs were scheduled in the week where their corresponding lectures were held, so that the topics were fresh in the students' mind. Additionally, cutting-edge research samples from the lecturers' own labs were brought in to the laboratory to mirror the experiments shown to the students during lecture, which they then took data on themselves. This was appreciated by the students.

Secondly, assessment was brought into line with the laboratories. Previously, even for laboratory-focused courses, the course grade had been based solely on the oral exam at the end of the course, which focused mainly on the theory taught. As such, the lab exercises took on an "optional" nature and were lowly prioritized by some students. For both CME and Nano 3, we now decided that 30% of the course grade would be based on the laboratory exercise, or rather its report. This was to be a journal article for CME (with Master and PhD students) while for Nano 3, students presented either a poster or a talk from one laboratory at a mock "conference", and wrote a journal article for the other exercise. We also allowed students the responsibility of designing their assessment topics (within limits), by stating that they could themselves choose a particular portion of the experiment they found interesting to focus their poster, article or talk on (as is done for a real publication). Lastly, to further incorporate research-based teaching, students were handed peer feedback forms such that they could give feedback at the end of the poster session to each other, acting as peer-reviewers (Appendix B).

Results and discussion

The redesigned quantum laboratory was deployed for the first time in Winter 2021 (CME, Blok 2) and Spring 2022 (Nano 3, Blok 3), almost back-to-back. The overall impact of the interventions were evaluated both via observation of student behaviour as they conducted experiments (by the lecturers and/or more commonly, the TAs) and by the standard course evaluation questionnaire. For this project, these were supplemented by a targeted, additional questionnaire in Nano 3, focused on the laboratory activities only (Appendix A) asking specifically about the students' experience with the lab, the source of any frustrations, and how they would change the labs if they had to design them.

The physical space

Since the TAs were the only constant across the improvement and enlargement of physical space (Fig. 1) before and after Covid-19 , the physical space was solely evaluated via TA impressions. One TA found the previous small room (K10) stuffy and had previously worked with building services to increase ventilation; another TA was also enthusiastic about the change:

> In room K10 it is possible to run one experiment at a time due to limited space. On the contrary, the new lab room can host up to three experiments at the same time,...[it] feels safer in the presence of cryogenic liquids, as the room is much larger and the windows makes the ventilation easier. I can say the students felt much more comfortable doing the experiments in the new room (more room as said before, and much more natural light). (TA, CME 2021)

A short aside about the multiple group aspect mentioned by the TA seems apt here. One aspect that we had not envisioned when changing to the newer lab space was that cross-team collaboration would be opened up. Now, students from two or even three groups could fit into the room, and as a result we now had teams that worked on two different experiments at the same time. Hence, we observed that a group that had done an experiment earlier could and did discuss, give tips and help their peers with experimental troubleshooting (much like a real experimental laboratory), leading to the epistemic enculturation, and collegial and intellectual social space that we had envisioned.

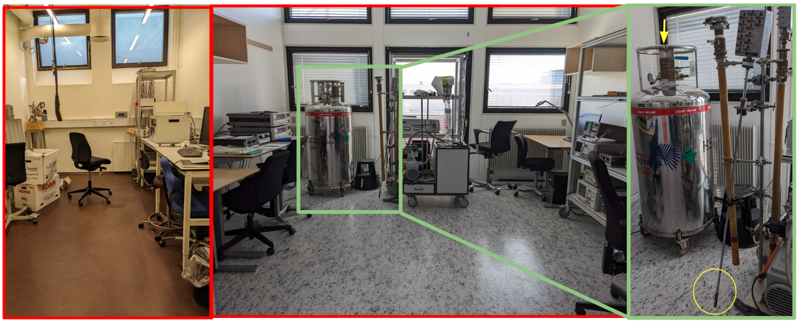

Figure 1. Redesigned lab in new physical space. Red boxes: left, old lab with a small, narrow space fit for a single experimental team to work in. Right, New room where different tables can have different experiments, which can be set out on the table instead of being hidden away in a cupboard. Inset and right green box: Vat of liquid helium, into which the sample at the end of the house-built dip-stick (yellow circle) is dipped, via a port (yellow arrow). This process boils off a lot of the liquefied helium, and this was performed by the TA before the students came to the lab. The helium is lost either way, in about two weeks.

The role of equipment

As described in the previous section, I had anticipated that equipment would be a major issue, as this was one of the things we were looking to improve. In order to cool down our experimental samples, we were using liquefied helium, a cryogenic liquid which boils off to gas daily. This meant that a container of it such as shown in Fig 1, allotted by our teaching budget, boiled off and became warm again in about two weeks, and the temperature inside became unstable a few days before. For both Nano 3 (24 students, 6 groups) and CME (8 students, 4 groups), students therefore had to cram in their measurements into a hectic two-week period. While we had envisioned flexibility and relaxed exploration of the labs as a rationale for off-hours labs, equipment constraints actually led to a time limit and less time to measure data. Student evaluations indeed highlighted this (Fig 2, third panel) and in their comments, for example: "It was unfortunate that the Helium caused the last lab excercise to be packed into 3 days". In addition, the probe inserted into the cryostat could only go to a limited magnetic field, also mentioned by several students. Almost 50% of students stated that their biggest frustration had to do with equipment (Fig. 1, top right), while in their free-text answers better equipment and more helium came up as by far the most common suggestions (Fig. 2, bottom left).

Lastly, cryogenic liquids can cause cold burns, and loading and unloading samples can cause the cryogen to run out faster. While students carried out a lab safety assignment, it was still considered advisable for us to load the sample into the cryostat once and for all before the lab was carried out. The students could not therefore do this hands-on part themselves, which some Nano 3 students mentioned:

> -Let students do as much as possible from the start to the end, also the preparation part.
> -I feel that we went into labs where everything was basically ready for us, and we just started the process. It would be nice if we could at least see how the setup was done.(For example how our samples were put in the liquid helium.)

This feedback strengthened our assessment that a stable, liquid helium-free cryostat was required for an efficient quantum laboratory, where the equipment limitations did not overshadow the experiment itself. Additionally, what we did not anticipate was that students would strongly prefer to see how a modern cryostat operated, and that they understood that what they were working with was outdated and somewhat artificial equipment. As a student in CME stated:

> A good idea would be to really see how a cryostat works and do this experiment as a whole class together with the lecturers, and then everyone would have to write a report on that [...] I would prefer to have the chance to see how a cryostat is operated. (Student, CME 2021)

Clearly, students at all levels considered learning about the cryostat, the main piece of equipment in most quantum laboratories, and doing every part themselves, as important as performing the specific experiment (a valid desire). During the project, we applied for such a helium-free, modern teaching cryostat (Appendix C, also showing a blueprint of the new lab), safe for students and capable of remaining cold as long as they want to measure. It has been granted to us and will be operational in 2023.

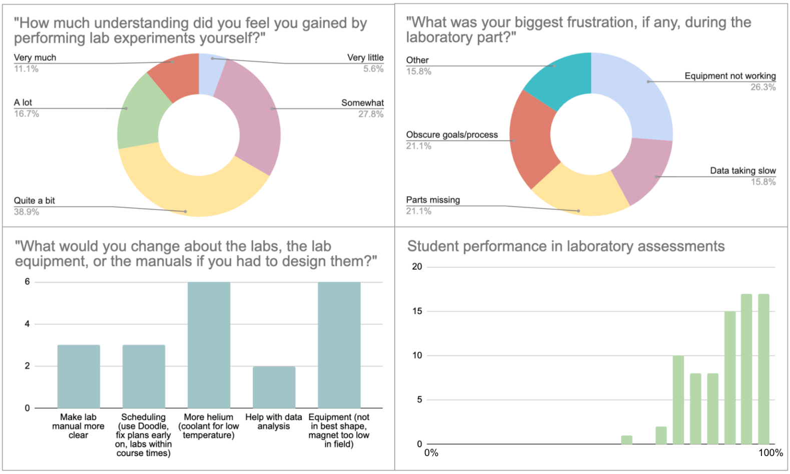

Figure 2. Results of questionnaire filled out by 18 out of 24 participating Nano 3 students, with (top row) answers to two specific questions (for exact wording, see Appendix A). Bottom row, left; points raised by students in text field asking for suggestions; the y-axis refers to the number of times a particular suggestion was mentioned. Bottom row, right; student lab performance exceeded expectations, clustering towards the highest part of the scale as assessed via student presentations, and outperformed the oral exam.

Assessment and practicalities

After this first run of the quantum laboratory, several practicalities related to timing became unexpectedly important, something I had not considered during the brainstorming phase. We had anticipated students would appreciate the flexibility of the lab timings, and indeed the TAs went out of their way to try to be available outside of normal working hours. Some students in CME appreciated this ability: “I like that we decide when to do the labs, and that there is a lot of flexibility around doing the labs.” while others were against the idea of coming to the laboratories outside of the listed hours. One student disliked the time taken for “doing the experiments off-hours” while another mentioned this adding to the workload: “There is listed hours for lectures, preparation and exercises in the course information. In which of these topics is the lab included?”. We had anticipated the lab as exploration time, a kind of “play” in some sense, and therefore tried to make it non-time-limited, but it seemed to have added to the cognitive load of the students. Some Nano 3 students were also unimpressed by this, as well as by having to change plans when the helium started to run out:

> -We missed lectures and exercise sessions in our other subject...the labs were outside the scheduled time for the course.
> -Lav lab inden for skemalagt undervisning. (*Make the labs within scheduled teaching.*)
> -I think they should be a more integrated part of the course itself. It was hard to find time outside the lectures to come to the lab.
> -Laboratory exercises could be scheduled better.

While these findings are contrary to expectations (where increased flexibility in lab times should empower students), they can possibly be addressed in a later iteration of the course(s). Presenting our rationale for doing it this way could clarify the didactical contract for the students. A more modern cryogen-free cryostat, and consequently smaller groups, will ensure more slots available such that the four students in each group do not have to rush to find a common time in a two-week period. In order to conduct experimental labs within the assigned time-schema, however, we will either have to replace lectures, or exercises, with labs. Currently, it is unclear how this should be done.

Alignment and assessment: This set of interventions was more successful. In Nano 3, we mentioned lab exercises and described the samples and measurements in lecture, and scheduled both experiments to run concurrently with the lecture topic addressed that week. Students were appreciative of this alignment between theory, method and experiment:

> -The other labs was interesting as well and it was really nice to see the things in action as well as seeing the theory work.
> -We got to see all the devices and make something ourselves in lab
> -It was a nice way of showing the theory.
> -I really enjoyed to see how big a part coding is in experiments, and how it can be used effectively
> -I believed it was some great lab excercises. They did a good job of illustrating some of the material discussed in the course.

A final intervention was to bring into alignment the assessments for Nano 3. A presentation (talk or poster) and a journal article now counted for a portion of the final grade, signalling that they were important components of the course. We also wanted to hand some control to the students:

First, they could now front-load their effort throughout the Blok instead of their entire grade being based on a twenty-minute exam at the end of the course. Second, they could choose which parts of the lab manual to focus on and which part to present as their research output. Two results were observed. One, students were very appreciative overall of this form of assessment. One student in CME directly stated, “I like that some of the final grade comes from the lab report”. In terms of the poster session, efforts were made to organise it like a real conference, with poster boards, large-format printed posters, and students and judges (the course lecturers) walking from poster to poster. An observing professor from the didactics department describes it as “...a poster session where students needed to present and explain results of experiments they conducted in the lab. The activity truly resembled a scientific conference”. Nano 3 students were similarly appreciative, both of the grading and of the student presentation form of assessment, more generally:

> -Synes det var et godt princip med poster session, og fremlæggelse (*I think it was a good policy, with a poster session and presentations*)
> -The poster sessions were nice and the lab report was interesting to write - generally it’s great that we were doing so many different things, it keeps it interesting.

As a last comment, I had expected that bringing this form of “real-life” assessment mimicking an actual conference and poster session, could be appreciated by students, but what surprised me was the high quality of these posters (example in Appendix D), talks, and articles; on completely new topics, and in some cases, with little more than a few days time to prepare. Student groups had clearly also rehearsed their talks and poster explanations, and gave thoughtful feedback to each other via the peer feedback forms (Appendix B). The close incorporation and alignment of lectures, labs and assessment was perhaps one of the successful outcomes of the first in-person year of the redesigned quantum laboratory.

Discussion and further work

Increasing the level of congruence, and alignment between theory and experiment in these courses, as well as designing a quantum science laboratory around the needs of diverse student populations (BSc, MSc, PhD, across engineering, physics, nanoscience) is a daunting task. The interventions and designs I chose lead to a few ambiguities. First of all, at multiple points, I have prioritized a higher standard of experimental learning, enculturation, and research output; this may not be the best approach for all, as evidenced by difficulties in scheduling. Bachelor students, especially, may be unused to such flexibility, as most of their courses are strictly within the time schema, but this at least currently seems indispensable for an experimental course. For a mandatory course, for many students this therefore leads to an increased course workload for a subject they may not continue to study further. The specific problem of scheduling laboratories around courses and lectures is a difficult one. This may be ameliorated by acquiring more fuss-free, safer equipment that is accessible during the entire course. However, on the other hand, students may need to go to other lectures, or stay after hours to complete labs.

From these laboratory courses, multiple excellent students at the NBI come in to the field of quantum physics, and carry out world-class research for their theses, in many cases publishing their work, with a work ethic and training they have received in experimental labs. However, it is worth asking, does this research-based approach to the laboratories overwhelm weaker students? Should laboratories always be optional, or only be part of a non-mandatory course?

In terms of further work, partly due to this project, a project grant from the Novo Nordisk Foundation will fund a teaching cryostat for the quantum lab next year. Ideally, the questionnaire developed for this project could be run again (with added questions, if necessary) to determine the impact of this major intervention, and which others are most useful over the years.

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A Specifically Designed Lab Evaluation

Kvantefænomener i nanosystemer (Nano3) B3-3F22 - Blok 3, 2021/2022 - Specific Feedback on Labs and Exercises

1 **How much understanding did you feel you gained by performing lab experiments yourself?**

- Very little
- Somewhat
- Quite a bit
- A lot
- Very much

2 **How prepared and/or confident did you feel while performing the experiments?**

- I was quite confused throughout
- I was confused to start but it started to make sense after a while
- It was straightforward, but I faced some problems
- It was pretty straightforward
- It was very clear to me what I was doing throughout

3 **What was your biggest frustration, if any, during the laboratory part?**

- The equipment not working
- Data-taking being too slow or cumbersome
- Parts you needed missing from the lab
- Unclear lab manual (please specify in free text field if so)
- It was obscure what you were doing and why
- Other (please specify in text field)

4 **What did you like best about the labs (you could also include the cleanroom portion in your answer)?**

5 **What would you change about the labs, the lab equipment, or the lab manuals if you had to design this component of the course?**

6 **Bonus question: what would you like the structure of the exercise sessions to look like and how long should they extend for?**

TILBAGE

B Peer Feedback Template

[Name, group name, and date:]
Write 1-3 things you looked for that would have made for an *excellent* poster presentation.

-
-
-

Reprioritize them in order of importance to you and condense to one to two words.
1.
2.
3.
Did the groups more or less meet your criteria? (Remember the short assignment timeframe you had!), write the criteria, a few words (or symbols: ☺,😐,☹ or √ ~,X etc), tear and give your feedback to the group.

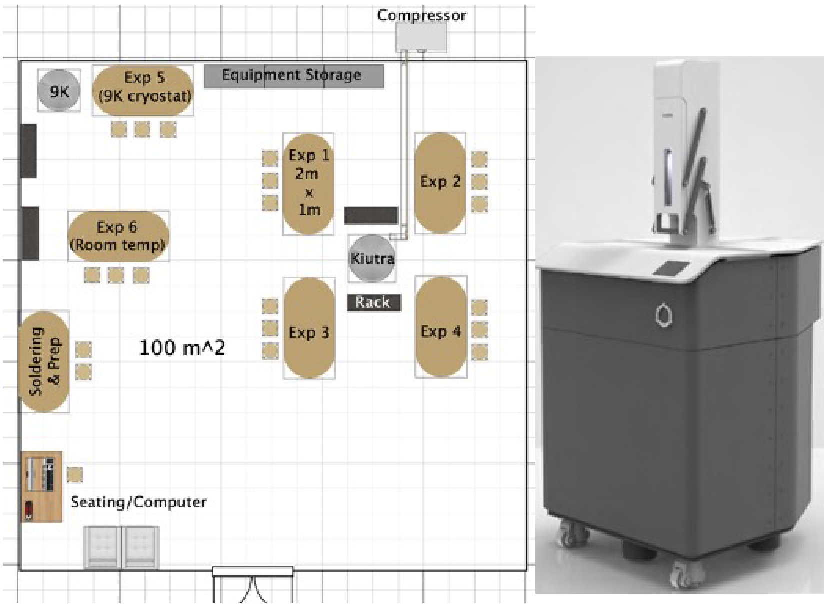
Group	Criteria 1	Criteria 2	Criteria 3	What is one thing you learned or liked?	What is a suggestion for improvement?
Group B					

Group	Criteria 1	Criteria 2	Criteria 3	What is one thing you learned or liked?	What is a suggestion for improvement?
Group C					

Group	Criteria 1	Criteria 2	Criteria 3	What is one thing you learned or liked?	What is a suggestion for improvement?
Group D					

Group	Criteria 1	Criteria 2	Criteria 3	What is one thing you learned or liked?	What is a suggestion for improvement?
Group E					

C Blueprint for New Quantum Teaching Laboratory



Blueprint for a modern quantum teaching laboratory, with a modern, cryogen (liquid helium) free cryostat ("Kiutra"). The room will have ample space for sample preparation, another cryostat, room temperature setup for other experiments not requiring low temperatures. There will be a data analysis station, comfortable seating, coffee and water to promote student engagement and make an appealing space for engaging with the experiments and the field in general.

D Representative Student Poster