Research Article

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The times of COVID-19 and beyond: how laboratory teaching evolved through the Pandemic

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Abstract: Pre–during–post lockdown waves, or how COVID-19 catalysed a change in practical chemistry instruction. This time-lined slogan reflects the University of Southampton's response to recent imperatives in chemistry education. During the pandemic students had limited access to laboratory training. However, laboratory time has always been precious, and educators constantly have to rethink their approach to lab classes; how to best assess practical learning goals and focus students' attention on the practical aspects during timetabled – and therefore time-limited – lab classes. The pre–during–post pandemic phases also govern the teaching split of our typical laboratory instruction, and the development during the three phases will be discussed. This article describes the evolution of the University of Southampton's laboratory training, how resources changed, how in-laboratory student participation improved, how the pandemic influenced the scheduling of teaching activities and informed a development of our assessment strategy. It considers where the rethinking process has led to so far while acknowledging that the current laboratory course is not the end of the process but an interim position, subject to future improvements.

Keywords: chemistry; chemistry education; laboratory work; impact of COVID-19 pandemic

1 Introduction

This article describes the development of undergraduate laboratory classes taken by students in their first and second year of tertiary chemistry education in the United Kingdom. This article discusses the timeframe – pre–during–post lockdown, and how COVID-19 catalysed a paradigm-shift in practical chemistry instruction. It deals with pre-pandemic planning for a revamped laboratory and laboratory course, summarising the changes that happened during the first three waves of the pandemic, and introducing the current state of affairs for first- and second-year undergraduate chemistry laboratory courses, which are standalone modules at the University of Southampton, UK.

Pre–during–post-lab: This timeline reflects on the recent imperatives in practical chemistry education (Seery, 2020), and describes a more practical skills focused approach to laboratory teaching, with an emphasis on preparation before the lab class, and learning during the lab class. Hitherto, students prepared before a laboratory class, performed the practical, and engaged in post laboratory activities. During the pandemic students had very limited access to laboratory training and at times none at all. Since laboratory time has always been precious, educators constantly had to rethink their approach to lab classes; how best to assess their practical learning goals and to focus students on the practical aspects during the timetabled – and therefore time-limited – lab classes.

Chemistry educators have thought about how laboratory classes should be delivered and what the emphasis of assessment should be since Reid and Shah (2007) published their paper about the role of a laboratory class in

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chemistry education. These authors argue that pre-laboratory preparation is important; actual laboratory classes need to touch upon practical and transferable skills as well as providing an intellectually stimulating link to the real world. Over the past decade, it has emerged that theory is best taught in lectures, workshops, and tutorials. It should be assessed through in-class tests and/or an end-of-semester examinations. Laboratory classes, on the other hand, would ideally be the place for teaching chemistry skills related to bench chemistry, the formulation of protocols, associated literature searches, and foremost, the execution of synthetic chemistry work and taking measurements for analysis. Additionally, it is the best context for a description of the practical work by the student and record-keeping, initially in laboratory notebooks (traditional or electronic). This is then followed by a concise summary in the form of reports, publication drafts or similar. In a modern setting this would be complemented by coding practice, an introduction to computational chemistry and chemical engineering essentials.

Therefore, practical skills directly related to chemistry as well as transferable skills that can be conveyed in a lab class should be assessed. This means a paradigm shift in terms of course design and assessment, from a written post-lab report to an in-lab skills-based assessment situation (Hancock & Hollamby, 2020; Veale et al., 2020).

It is equally important to design laboratory courses and environment that are inclusive, *i.e.* accessible to all students, and great effort is being directed to addressing this topic, as recently described by (Egambaram et al., 2022). This applied particularly during the lockdown phases of the pandemic when students were taught online and were lacking practical, hands-on education. This led to a diminished confidence in the execution of practical tasks, as well as formulating and defending an argument or opinion in a face-to-face environment. This is, however, an important task that features prominently in laboratory environments and is a transferable skill applicable to many professional situations in the work life after university education. Laboratory courses, like all other educational settings, should therefore seek to accommodate students in all circumstances.

Teaching during the first lockdown phase of the pandemic (April–May 2020) led to a rapid development in the way knowledge and practical skills are conveyed, using both online and face-to-face settings for instruction. Reflections on teaching undergraduate classes partly online have been discussed (Logothetis & Flowers, 2020) as well as online facilitated student collaboration in Science Foundation year cohorts (Read et al., 2022a), and these outcomes underpinned developments described in this article.

Students often perceive education differently from their teachers. It is therefore important to consider the student voice. Constructive feedback from students about their experience and their perspective on the teaching provision is therefore of paramount importance to the design of new courses (George-Williams et al., 2018; Read et al., 2022b). The improvements described in this article have been strengthened by student feedback which was gathered throughout the described stages in an informal way, for example through feedback from senior tutors, personal tutors and through staff student liaison committee meetings, where students directly advise their educators and chronicle their experiences.

Additionally, lab class exit polls and casual discussions with students during or after their classes were also used to obtain feedback.

Through the lens of the practical perspective, the *pre–during–post* division also governs the teaching split of the typical lab instruction:

- The PRE-LAB phase involves preparation for the practical work through a virtual learning environment and library resources. During this phase, that is similar to flipped lecture-instruction, the background theory is addressed, and laboratory techniques are explained.
- During the IN-LAB phase, skills are developed and tested while a practical is performed, the learning accentuates a “doing, applying” mode.
- In the POST-LAB phase results and knowledge are consolidated and reported or presented.

In this article, I describe the setting before the pandemic, how laboratory teaching adapted to the lockdown and which improvements were introduced once lockdown had ended.

2 Pre-pandemic: status and planned improvements

A virtual learning environment, VLE, (Blackboard) is available and has been used in chemistry laboratory teaching since 2007. The resources initially included short videos that demonstrated laboratory techniques, but evolved over time to comprise laboratory scripts, narrated PowerPoint presentations and finally multiple-choice quizzes. Supporting resources like analysis of data or assistance with interpretation of spectra complemented the provision. By the time the pandemic started, the teaching laboratory had gone paperless, and submissions of reports were facilitated by the VLE.

Planned improvements during this phase centred around feedback and potential outsourcing the development of future supporting videos with integrated feedback. Teaching fellows in the department updated the practical content annually and regularly added new and/or improved resources to the VLE.

On the infrastructure side, the planned improvements encompassed a modernisation of the instrument suite, increased sustainability of the estate and facilities, and increasing inclusivity beyond accommodation for hard-of-hearing users. More space later facilitated the mandated inter-person distancing during the pandemic; new ventilation increased air-exchange rates.

The lab classes cycled between laboratories (location) and inorganic, organic and physical chemistry (topics), totalling 80 h (Table 1). The practical courses constantly evolve, but particularly in view of the pandemic more profound changes were necessary. Table 1 describes the situation before the pandemic; phase 1 spanning the 1st and 2nd lockdown in 2020, and phase 2 around the 3rd lockdown in early 2021.

The assessment included reading the script, watching videos and presentations (formative) and a multiple-choice quiz (summative), as part of the prelab preparation. In the lab class the laboratory notebook and samples were evaluated (summative), and a report had to be submitted after class (summative).

Over the years it has become evident that the assessment load was high and needed reducing, and students benefitted from additional support during the post-lab phase. Therefore, it was anticipated that both would need changing in the new laboratory course: The practical provision was revised to reduce both, the time needed per experiment and the number of assessments. This allowed for extra support during the lab class, by way of supervised write-ups and analyses.

3 The times of corona: during the pandemic and refurbishment

From October 2020, the laboratory classes ran initially as before but during the end of semester 1 students were given the opportunity to travel home before the end of the winter term (which ran socially distanced till December 2020) with a view to staggering departures during the last two weeks before the end of year vacation. Consequently, only a very limited amount of teaching was lost *i.e.* while teaching continued online, attendance monitoring, and submission of work were suspended; take-up was low due to circumstances.

The pandemic hit with full force during semester 2 (January to July 2021) and it was decided during term 2 (late January to mid-March 2021) to timetable lab classes towards the end of term 3 (late April to late June 2021),

Table 1: Lab class schedules before, during, and after the pandemic.

Pandemic phase versus times	Before pandemic	Phase 0 Apr–May 2020	Phase 1 Oct–Dec 2020	Phase 2 April–June 2021	After pandemic from Oct 2021
Scheduled contact time per semester	80 h, 10 weeks	80 h planned[a]	80 h, 10 weeks	64 h, condensed into 2 weeks	80 h, 10 weeks
Length of individual lab classes	1 day (2 × 4 h)	Online during lockdown	Socially distanced; 1 day (2 × 4 h) a week,	Socially distanced; 4 days (2 × 4 h) a week	Day 1: 4 h/5 h Day 2: 4 h/3 h

[a]Some students had connectivity issues and did not engage in all activities. Attendance was not monitored.

Table 2: Pre-, in-, and post-lab activities at different stages.

	Before the pandemic	Phases 0 & 1 2020	Phase 2 2021	After pandemic
Pre-lab	Narrated PPT, techniques video, script, quiz	Additional provision of data during lockdown	Streamlined videos, focus on lab skills, less/or no theory	Analysis & technique videos, literature, risk assessment, video quiz, smart worksheet
In-lab	Compulsory attendance. Notebook, sample, experiment	None during 1st lockdown. Socially distanced during 2nd lockdown	Experiment, data recorded by technician, processed by academic, brief report by student	Experiment, acquisition and analysis of data, feedback, brief report or lab skills
Post-lab	1 report per week	1 short report	1 full report	1–2 reports or presentations per semester

thus front-loading lectures and similar activities that could be delivered online. The laboratory schedule was changed completely in this phase 2 to two weeks of classes (4 days per week) with one fallow week in-between. Like in phase 1, students were allocated fume cupboards and benches, while staff collected samples, acquired and reprocessed data to maintain proximity regulations and cross contamination at central instruments. This arrangement afforded time to complete the delayed refurbishment of the teaching laboratories and allowed in-person lab classes without too big a loss of contact time (16 h, see Table 1). This paradigm-shift in the way classes were scheduled was enforced by COVID-19 lockdowns as timetabling lab classes was too inflexible.

However, the content, resources and assessments had to be updated at short notice and with little time to adapt to new online tools.

The most significant changes from the student perspective were the reduction of the assessment load and the concentration of laboratory work (Table 2). It was acknowledged that only voluntary and formative pre-lab preparation would be possible, and that only one summative post-lab report per week would be reasonable. In that sense the pandemic triggered a radical rethink of assessments that would not have been envisaged as feasible without this externally imposed catalyst for significant change.

The feedback on these changes was split, with some students favouring the focus on laboratory classes in a short period of time, whereas the others found this stressful. Both student groups noted a lack of time for a deeper engagement with the subject of each practical experiment.

These changes and the feedback promoted a fresh review of the teaching and assessment style, and with substantially improved space, that made the laboratories and associated break-out rooms physically more accessible, a better and more inclusive approach was designed. The large size and new infrastructure in the laboratories reduce aural and visual cognitive load, has advanced audio-visual IT installations as well as height-adjustable benches and fume cupboards designed for mobility-impaired users.

4 Post-pandemic: in-person lab classes

During the second year of the pandemic, a substantially modernised and increased laboratory area allowed socially distanced lab classes without the need for condensing the schedule.

Instead, a block approach was adopted with a more synthetic chemistry-oriented half, and a more analytical, computational and coding half. The teaching section split was lifted, and 5-week blocks of 8 h a week, divided over two days in either a 2×4 h or a $5 + 3$ h combination.

Together with a reduced practical workload (Table 2), this made the course much more accessible and inclusive to users of various needs. In the first post-pandemic year this arrangement also allowed a substantially increased intake while updating the practical provision to include minor design and assessment improvements.

The current teaching approach and assessment regime is described below with initial student feedback.

4.1 Pre-lab period

This is now designed for every practical or experiment to include a combination of formative and summative tasks with a view to prepare for the lab classes so that discussions and practical work can commence directly at the start. The pre-lab tasks mix risk assessments, multiple choice quizzes, smart worksheets, short video lectures, literature searches and design of laboratory protocols, with introductory presentations and techniques videos. Pre-lab assessment is based on around a third of the selected activities that form part of the summative assessment *e.g.* smart worksheets, video lectures, and provides immediate feedback to facilitate students' preparedness for the practical lab class.

Compared to before and during the pandemic, this pre-lab preparation requires more time and effort from students. It was perceived as being more intense and thus students' opinion was divided, although the benefit of being well prepared for the practicals is recognised together with better and self-guided time-management opportunities.

4.2 In-lab period

The split into roughly two half-days, on successive days, has proven successful, in that it provides respite compared to a full day. It also allows a catch-up of previously taught content, that might be identified during the first session. This aspect is valued throughout the cohorts. This split necessitated a dynamic approach, especially to synthetic procedures, so that Process Oriented Guided Inquiry Learning (POGIL) approaches or initial presentations can be accommodated. Many experiments have been shortened and the second session is often dedicated to data analysis and interpretation. Alternatively, discussions can be scheduled during an experiment at suitable times, *e.g.* after setting up and starting a reaction, as longer procedures can be extended overnight in the new module.

The second session now offers the option for a supervised analysis and writing a report, presentation, or similar submission, which would be finished in most cases during the session, rather than afterwards. It leaves ample opportunity to provide 1:1 verbal feedback and to clarify previous online feedback directly with the academic in the laboratory. Students can opt for an off-campus approach outside the laboratory, which exclude the possibility to seek immediate help. Where a submission is required, it is a brief, in-lab submission, that is subject to summative assessment.

However, with direct in-person contact permissible, the post-pandemic phase now features a direct lab-skills assessment, either of practical skills, or data reprocessing skills, or analysis/interpretation skills. This aspect is set to increase in future and will contribute to a reduction in report-type submissions, the number has been halved compared to previous cohorts.

This is seen positively and described as desirable by the educators; however, it is acknowledged that it can increase anxiety.

4.3 Post-lab period

This final part of a lab practical is now used sparingly (Table 2), to provide more time for other teaching activities, to leave time for the next pre-lab tasks, and to practise skills that will be taught in greater detail at a later or different stage, *e.g.* full laboratory reports and publications or formal proposals.

As has been shown during the phase 2 of the pandemic, a concentrated effort can be elicited, if this summative assessment is used sparingly, and currently it is the case once or twice per semester only – a reduction of 80 % compared to pre-pandemic times. This was received well by all involved parties.

5 Conclusions

The upgraded laboratory infrastructure and improved timetabling of classes has been well-received by students who experienced more than one setting, *i.e.* "before or during pandemic" and "afterwards", has encouraged disabled persons to apply for studying at the University of Southampton, and has increased the accessibility for everyone.

The pandemic has accelerated this development as it forced a rapid change in timetabling and allowed the modelling of several schedules during lockdowns. COVID-19 has had a positive effect through catalysing a re-evaluation of the teaching approach and provision. In this way it has driven a change greater than originally envisaged through the refurbishment project. Partly this was supplemented by enhancing an already well functioning virtual learning environment with more, new and improved online content. This has largely been received positively by teaching staff and students. This project will be further developed in future, and continued progress will be evaluated through constructive feedback from all involved parties. *The times of COVID-19 and beyond* documents the evolution of Southampton University's chemistry laboratory training: how the resources and types of resources changed, how student participation in the laboratory improved, how the pandemic influenced the positioning of teaching activities and informed a development of our assessment strategy. In summary, it focusses where the rethinking process has led to so far – acknowledging that also this stage is not the end but an interim position, subject to future improvements.

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