TRANSFORMING TEACHING
INSPIRING LEARNING

Innovative pedagogies series:
A dynamic laboratory manual

Pre-lab online support for practical Chemistry

Professor Dudley E. Shallcross, Jennifer L. Slaughter,
Timothy G. Harrison and Nicholas C. Norman

University of Bristol

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Introduction

Undergraduate practical teaching in Chemistry up to c. 2005

Practical chemistry: what is it for? As practitioners we have treated laboratories as mystical places where students will understand and be excited by bubbling potions and magical black boxes. In the past we might have been allowed to continue in this vein, wilfully neglecting the students' perplexed faces and trusting that simply being in the laboratory environment will be enough. But laboratories are expensive; students seemingly eat through glassware, lap up stocks of chemicals and emerge from these supernatural places with little more than an impression of smoke and mirrors, refusing the osmotic pressure of 'learning'. We have faced the righteous forces of student fees and school management, rightfully demanding we deliver quality to the masses. More often our students leave university never to step foot in such spaces again. So now we must provide worthwhile time in these precious laboratories and give our students much more than an impression of alchemy. Eleven years ago, this is what Bristol ChemLabS, a HEFCE CETL in practical Chemistry set out to do.

Practical Chemistry has always been an important component of the teaching of Chemistry at both post-16 and undergraduate level in the UK; although not necessarily carrying much weight in terms of assessment. Reid and Shah (2007), remind us that there was a need to produce skilled technicians for industry and highly competent workers for research laboratories (Morrell 1969; 1972). However, such demand is not evident in the UK in the 21st century as automation has become prevalent in industry. Indeed, it is well recorded that the majority of Chemistry graduates never enter a laboratory again and those that do go into research require further specialised training (Bennett and O'Neale 1998; Duckett *et al*. 1999; Hanson and Overton 2010). Therefore, the notion that the prime purpose of practical Chemistry at tertiary level is to train a professional chemist, is somewhat inappropriate. What, then, is the purpose of laboratory work in an undergraduate Chemistry course? There have been many attempts to answer this question: Johnstone and Al-Shuaili (2001) provide a comprehensive review of the whole topic of learning in the laboratory and note five goals for science laboratory instruction to arouse and maintain interest: skills, concepts, cognitive abilities, understanding the nature of science, and attitudes (Johnstone and Al-Shuaili 2001).

Despite these laudable aims, various critics have raised problems with the teaching of practical work. Firstly, it is very expensive in terms of chemicals, equipment, demonstrators, technical staff and the dedicated use of expensive, bespoke teaching space (Hawkes 2004; Carnduff and Reid 2003). Secondly, it is inevitable, due to equipment optimisation, that students will rotate around the laboratory during the course of the year and carry out a set of practicals in a variety of orders, most likely being out of synchronisation with lecture courses. Hence, university students' reactions to practical work are often negative, and this may reflect a student perception that there is a lack of any clear purpose for the experiments: they go through the experiment without adequate stimulation (see for example, Johnstone and Letton 1988 and 1990). Finally, the paper-based laboratory manual often feels like a recipe book, and students often only start to read it after they have entered the laboratories (Shallcross *et al*. 2013a; 2013b). The demand that the laboratory manual contains clear instructions and good diagrams is high (Rollnick *et al.* 2001a; 2001b), but when done well a laboratory manual has a dramatic positive effect on student learning and satisfaction.

In response to these demands, innovations in practical Chemistry teaching and re-learning of good practice began to emerge. For example, pre-laboratory work clearly had a very positive impact on the learning outcomes of students (Johnstone *et al*. 1994; Johnstone *et al*. 1998; Brattan *et al*. 1999; Nicholls 1999; Reid and Shah 2007; Shallcross *et al*. 2013a; 2013b). Pre-laboratory work signposts the key techniques and practical skills that will be encountered and can allow understanding to increase simply by reducing information overload. Exercises are completed before the laboratory starts and aim to prepare the mind for learning. Both paper-based (Carnduff and Reid 2003) and some computer-based exercises were in use by 2000

(Johnstone *et al*. 1998; Nicholls 1999; McKelvy 2000; Tomlinson *et al*. 2000). In a test of understanding, the pre-laboratory exercises were found to increase performance by around 11%, while it was found that students were dramatically more positive about laboratories (Johnstone *et al* 1998). The use of videos to demonstrate the assembly of equipment was also trialled successfully (Tunney 2009).

Students enjoyed practical work in support of their teaching, noting that the subject is predicated on experimental investigation and verification (Sneddon and Hill 2011). These authors noted that in many cases, secondary school teachers had had a very positive influence on students through practical teaching and that it was essential to build on this foundation, that is to provide a smooth transition from post-16 teaching through to tertiary level.

How this practice evolved (creating an enhanced online learning environment)

The tradition of using laboratory work to support theory taught in lectures under the artificial sub-divisions of organic, inorganic and physical Chemistry had been in use at Bristol. Large cohorts of around 200 undergraduates would attempt a circus of practical activities, housed over three floors of laboratories (organic, inorganic and physical) each holding around 100 students. For most students, the practical work undertaken would be out of sync with the lecture course, and in many cases the appropriate theory underpinning the practical would not have been covered yet. This was unsatisfactory for all concerned.

Typically students would arrive at the laboratory not knowing what they were about to do and why. Students would open the manual in the laboratory and start reading about the experiment. They would then follow the instructions systematically, as though they were a recipe, without appreciating why they were doing what they were doing. Consequently, little learning was being exercised in the laboratory. The prime purpose appeared to be to obtain the results to take away and work on at home. Only after the labs would students discover that some key step was omitted, or needed explanation, and students would spend an inordinate amount of time on their post-labs write-ups. More time was wasted through repeatedly asking the demonstrators how to set up or use basic equipment such as condensers. Health and safety awareness is always paramount; students signed a form stating they understood the associated hazards but did they understand the hazards inherent in a technique?

In 2005, the Higher Education Funding Council for England (HEFCE) awarded the University of Bristol a grant of £5.5M to fulfil three aims: i) to transform its traditional 1960s-built teaching laboratories into modern, 'state-of-the-art' laboratories (a further £16M was contributed by the University to modernise the departmental buildings for this purpose); ii) to redesign the undergraduate laboratory course; iii) to expand its Chemistry outreach provision. Bristol ChemLabS is the result; a HEFCE-funded Centre for Excellence in Teaching and Learning (CETL) in practical Chemistry that is based within the School of Chemistry at the University of Bristol (Shallcross *et al*. 2013a; 2013b). These days ChemLabS is synonymous with practical Chemistry, for both undergraduate learning and outreach engagement.

Securing funding to improve the students' experience with up-to-date laboratory facilities and instrumentation afforded the impetus to re-think the laboratory work that was carried out in them. The decision was taken to focus on the development of practical skills required by a 21st century chemist in the early years of the degree course. This led to the virtual abandonment of the artificial sub divisions and to condensing the teaching laboratory space from three labs to two.

Even this reduced laboratory space is expensive; more effective and efficient use of such space could be achieved if the students arrived having prepared before the lab session, confident in their knowledge and able to start straight away. The aim was to create a situation where students arrived with competence and confidence, understood the techniques and asked questions about the Chemistry involved and where issues about the experiment were resolved within the lab environment, through discussion. Two key strategies were adopted to achieve this aim; the redesign of the laboratory course itself and the implementation of online support for practical teaching.

The course was redesigned to focus on the sequential development of skills; alleviating the necessity for practicals to align with lecture courses. First year laboratories focused on creating a 'level playing field' for incoming students, developing basic practical skills and laboratory awareness. The disconnection of laboratory classes from lecture courses allowed the introduction of experiments that demonstrated the interdisciplinary nature of techniques to be incorporated into the second year laboratories, earlier than historically possible. In turn, establishing advanced techniques in the second year, enabled the third year to focus on developing students as independent researchers, who, with a broad base of technical knowledge could choose their own techniques and methods of analysis.

Table A: The skills-focused redesign of the laboratory courses which builds sequentially from one year to the next

Laboratory course / Skills	First year	Second year	Third year
Practical	Common techniques	Advanced techniques	Industrial research techniques
Professional	Laboratory safety; keeping a lab book	Risk assessment	Independent risk appraisal
Analytical	Data manipulation	Generating and analysing data	Choosing appropriate analytical methods
Reporting	Recording and reporting results	Writing scientific reports	Discipline-appropriate scientific reporting
Transferable	Laboratory attitude	Time keeping and organisation	Time management, multi-tasking and independent working
Research			Identifying suitable techniques and working with failure

Removing the link between lectures and laboratories necessitated additional support for students to introduce the theory of experiments. This, in hand with the desire to make more effective use of the laboratory space and time, required moving the balance of the student's independent work to be completed ***before*** rather than ***after*** practical sessions. To do this an online support resource was created which would allow all students asynchronous engagement with the material required for any particular lab. This became known as the Dynamic Laboratory Manual (DLM).

The DLM is a 'one-stop shop' for experiment-supporting resources. In advance of the lab session, the student will engage with the introductory theory, the practical procedures and the associated techniques. It gives students basic information such as which part of the laboratory they will be working in and introduces them to the specific, individual pieces of kit they will use. The content is presented in a variety of formats: videos, simulations and interactive 'explores' of photographs, as well as printable manuals, and formative and summative tests. However, the DLM does far more than just allow students access to the work before the lab. Through the DLM, each week, about 450 undergraduate students can access different labs, with different pre-lab assessment, at a time which is appropriate to them and in a manner appropriate to each individual (i.e. one student might know how to do a reflux, but not how to switch the water supply on, whereas another might need to revisit the recrystallization videos several times).

The automated assessment of pre-labs which this system allows, also means these 450 students can be assessed across the multiple different pre-labs, and as a consequence, staff workloads can be decreased (i.e. demonstrators don't spend time signing off people's pre-lab work).

Videos are broken down into several, navigable short sections and are accompanied by key points explaining why they need to be done in the way they are described. These key points are provided as bullet points alongside each section of video, and are described in an accompanying voice-over which is also available as a transcript. Such information is seldom found in text books and is usually only available verbally from instructors or demonstrators. Importantly, all the models in the videos are those actually available in the labs.

Interactive simulations are available for all procedures from the use of rotary evaporators, reflux apparatus and thin layer chromatography to glove boxes and Schlenk lines.

Animations of the mechanism for the reaction, where appropriate, are included to illustrate difficult theory (e.g. the movement of electron density is animated through moving curly arrows).

Online tests, formed randomly from libraries of multiple-choice questions, form part of the assessment for the practical. The answers must be submitted online up to 24 hours ahead of the practical class. The same is true of the safety quiz which must be passed at 80% or above if students are to be allowed into the laboratory. The assessments are negatively marked and students are allowed two attempts at the test.

The marks allocated to these tests, as well as attendances, seminar work, examination results and feedback, are collected and made available through a bespoke 'marks, attendance and feedback' (MAF) software programme.

To date, the DLM comprises 59 topics with 95 videos, interactive explores and simulations covering laboratory techniques, and an additional 51 interactives, explorations and simulations covering appropriate theory to situate pre-laboratory work. It is, in essence, a library of techniques illustrated through enhanced content. The variety of formats in which techniques are presented creates a highly accessible online manual for learners.

The content is highly structured; the library of laboratory techniques is separated into key areas which approximate to basic, intermediate and advanced level skills. This library has been used to enhance the content of each experiment in such a way that students are able to build their level of knowledge as they progress through the laboratory course. Content from the basic DLM is covered within the first and second year laboratory programmes but elements from the intermediate and advanced techniques are interwoven through the course. Conversely, for advanced laboratories catering for third year students or for postgraduates, advanced level techniques are the focus, but the ability to link in content from the basic and intermediate levels allows a revision for students and an enhanced training aid, for example 'basic' Chemistry and Biochemistry techniques can be utilised for postgraduate training where there are gaps in undergraduate training.

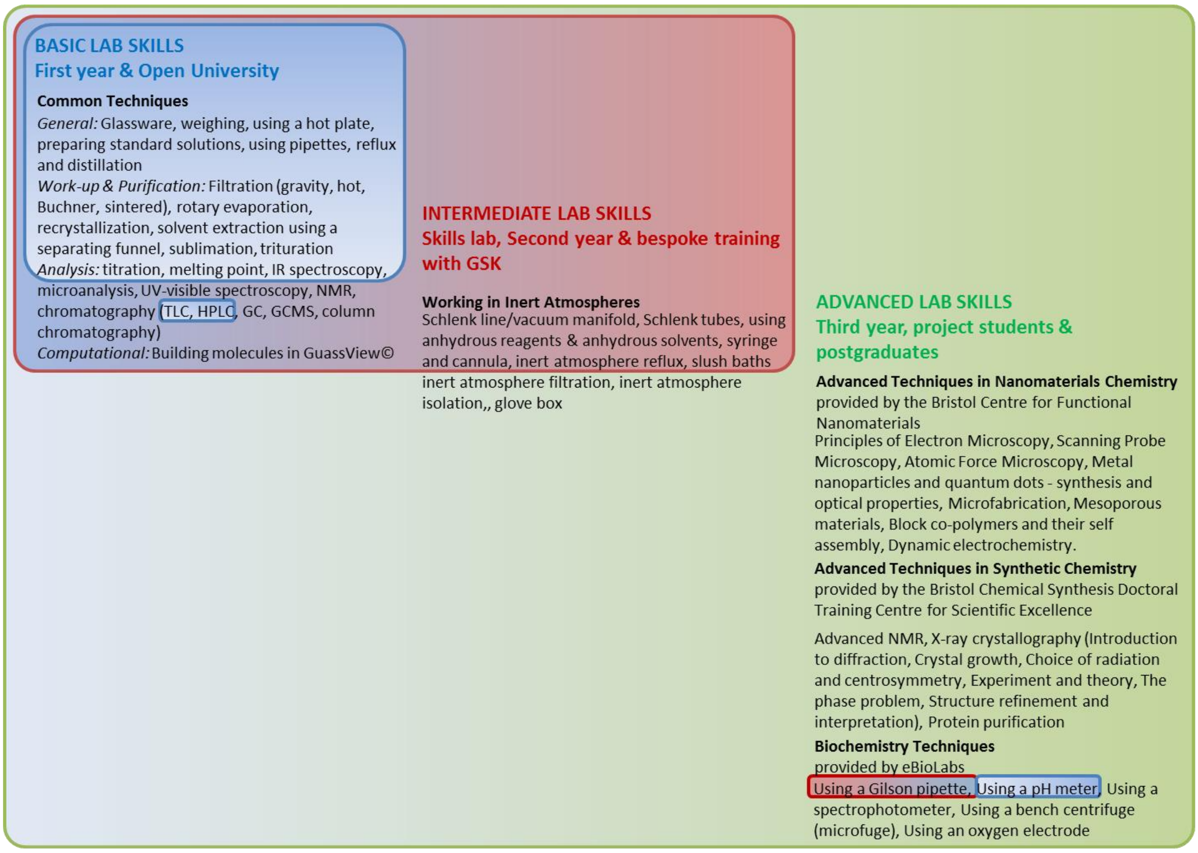


FIGURE A. THE OVERLAPPING MANNER IN WHICH DLM CONTENT IS UTILISED THROUGHOUT A STUDENTS' STUDIES.

Constructing an online library of resources allows flexibility within this structure. Students are provided with content specific to their laboratory course but are able, at any time within their studies, to go to the library and look at more advanced content, content from other courses, or to revise content. Third year students are directed to material from postgraduate doctoral training centres or from another degree course, for example Biochemistry, evidencing for the student their own level of skill and the breadth of their scientific training. Thus, the online environment of the DLM not only supports laboratory practice but also supports and fosters independent learning.

The content is differentiated, depending on the level at which the content is to be delivered. Basic and intermediate content tends to have interactive *diagrams*; a simulation of kit which is diagrammatic, rather than a photo. Importantly this allows gases to have visible flows (Figure B) and colours (Figure C), for example.

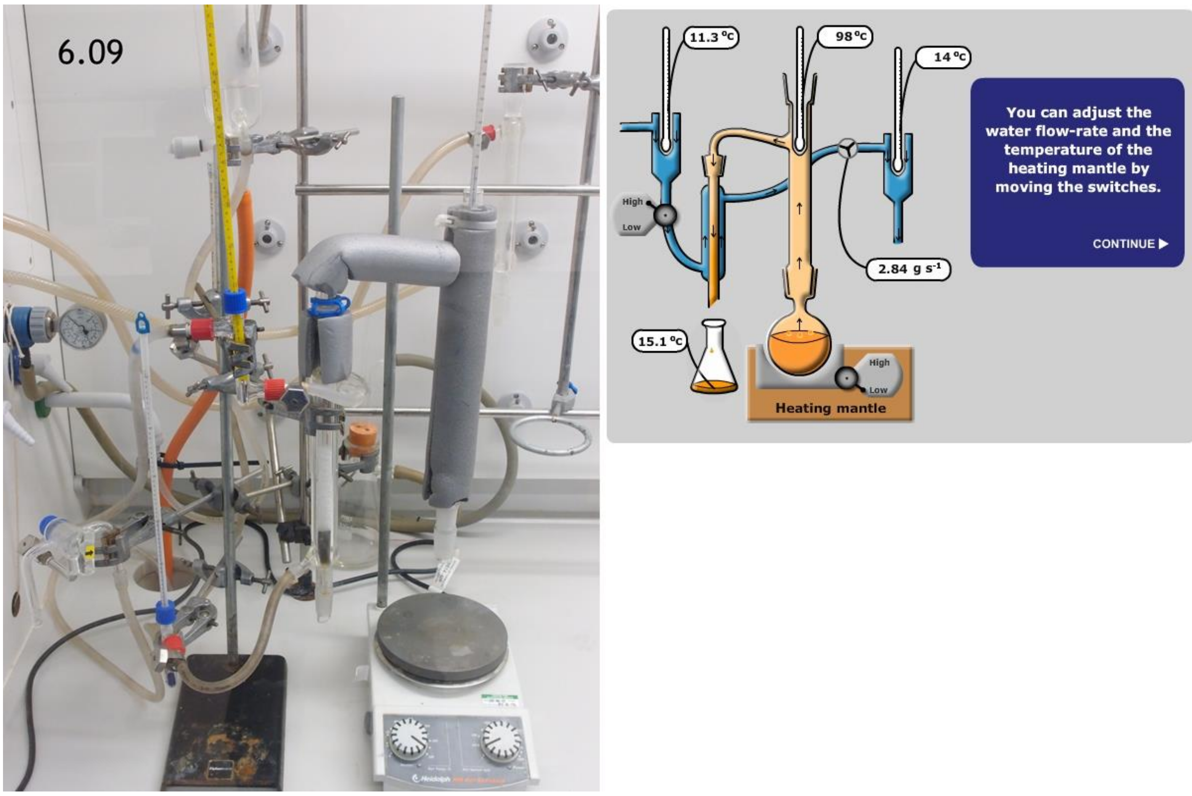


FIGURE B: THE FLOW CALORIMETRY APPARATUS, WHICH IS USED BY FIRST YEAR UNDERGRADUATE STUDENTS (LEFT). MET IN THE LABORATORY FOR THE FIRST TIME, SUCH A PIECE OF KIT IS A "BLACK BOX" TO STUDENTS. HOWEVER, USING A DIAGRAMMATIC SIMULATION (RIGHT), ALLOWS STUDENTS TO VISUALISE IMPORTANT ELEMENTS OF THE PRACTICAL THAT WOULD OTHERWISE BE INVISIBLE, SUCH AS THE DIRECTION AND SPEED OF WATER FLOW, THE FLOW OF GAS AND THE SITES OF TEMPERATURE READINGS.

This is presented along with *pictorial*, real life content such as videos or 'photograph explores'. The latter presents a photo of the kit with videos to explain each particular part which 'come to life' when a student interacts with a certain tap or button, along with *written* information.

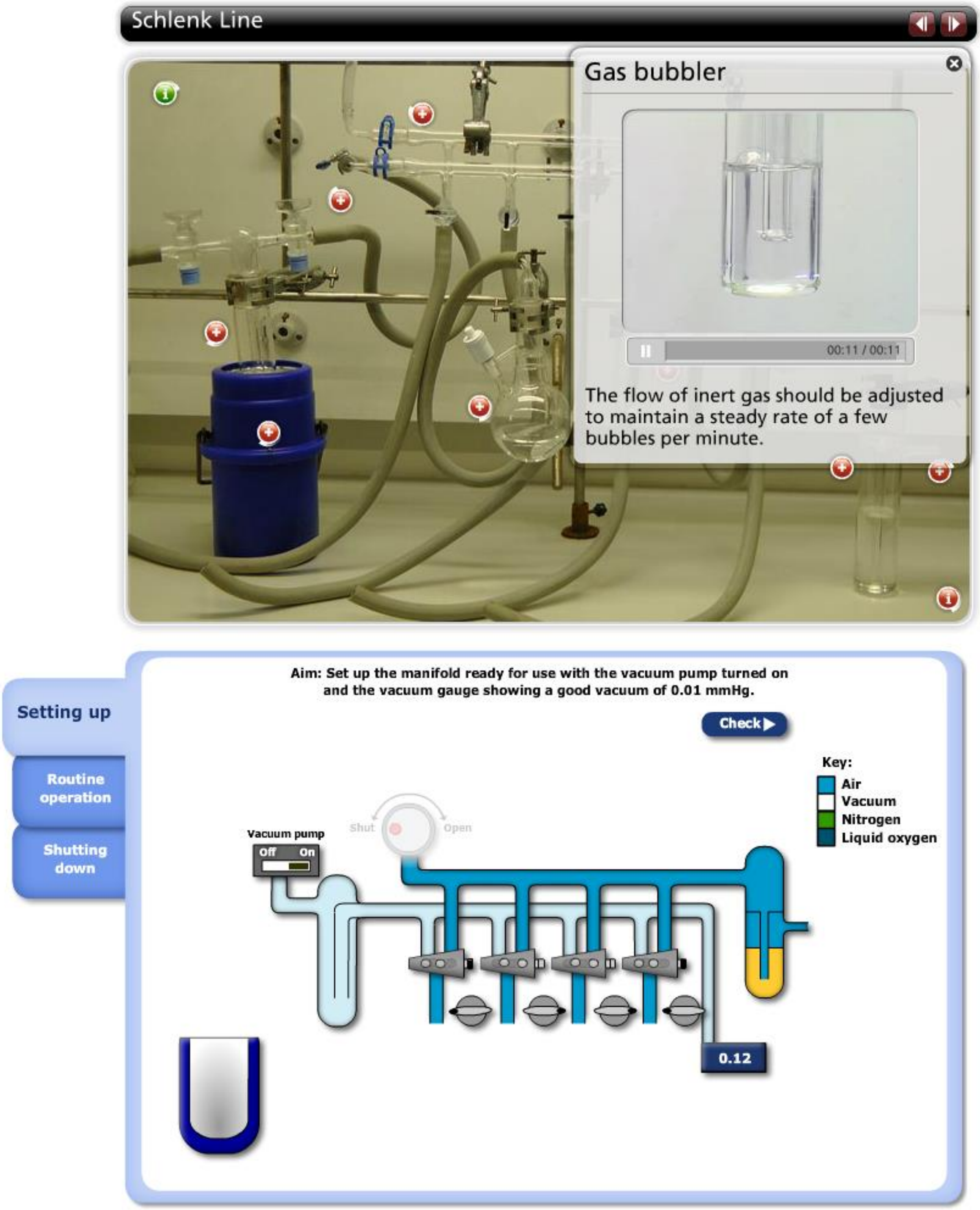


FIGURE C AN EXAMPLE OF A PICTORIAL 'EXPLORE' (ABOVE) AND AN INTERACTIVE SIMULATION (BELOW) FOR SCHLENK LINE TECHNIQUE. THE PICTORIAL EXPLORE IS ENHANCED WITH VIDEOS WHICH EXPLAIN KEY CONCEPTS RELATING TO PARTICULAR PIECES OF THIS MORE COMPLEX PIECE OF KIT. FOR EXAMPLE, THE NITROGEN BUBBLER IS ACCOMPANIED BY A VIDEO SHOWING WHAT THE RATE OF BUBBLING SHOULD BE, HOW TO OBSERVE IT AND HOW TO ADJUST THE RATE. IN THE INTERACTIVE DIAGRAM, THE PRESENCE OF AIR IS INDICATED WITH VARYING SHADES OF BLUE.

Creating diagrammatic forms of kit which allow students to practice the experiments not only allows the visualisation of phenomena which cannot be seen in the laboratory but also enhances a student's appreciation of the hazards involved with the technique. For example, using varying shades of blue to represent the amount of oxygen in a Schlenk line can allow visualisation of how incidents may occur and how they can be avoided.

It is increasingly accepted that failure is an important aspect of learning (Nietfeld *et al*. 2005; Duckworth *et al*. 2007); allowing students to rephrase their own ideas, dealing with misconceptions, and to elaborate their own learning, allowing development and growth. However, failure in the lab can often be synonymous with hazardous situations and thereby near impossible to allow. Simulations can provide a safe environment in which students can fail and all the DLM simulations have the ability to 'fail' the experiment; for example, a student can condense oxygen in the cooled trap of a Schlenk line, drop the flask of the rotary evaporator into the water bath or cause items placed in a glove box port to implode (Figure D).

FIGURE D. EXAMPLES OF FAILED ATTEMPTS TO COMPLETE TECHNIQUES EXIST FOR ALL SIMULATIONS AND AT ALL LEVELS. ON THE LEFT, A VESSEL WAS PUT INTO THE GLOVE BOX WITH A NITROGEN ATMOSPHERE, RESULTING IN AN EXPLOSION OF GLASS IN THE GLOVE BOX PORT. ON THE RIGHT, THE STUDENTS HAS OMITTED TO PLACE A KECK CLIP ON THE FLASK NECK AND THUS THE FLASK HAS FALLEN FROM THE ROTARY EVAPORATOR AND INTO THE WATER BATH.

The structured formation of the content allows advanced level content to rely on an understanding of the kit which has already been established. For example, for advanced NMR or scanning probe microscopy, animations and interactive content concentrate on the theory and manipulations not previously encountered. Where an advanced concept is not known, such as H tubes for crystal growth or the interaction of nanoparticles with light for example, the videos, explores and animations are used (Figure E).

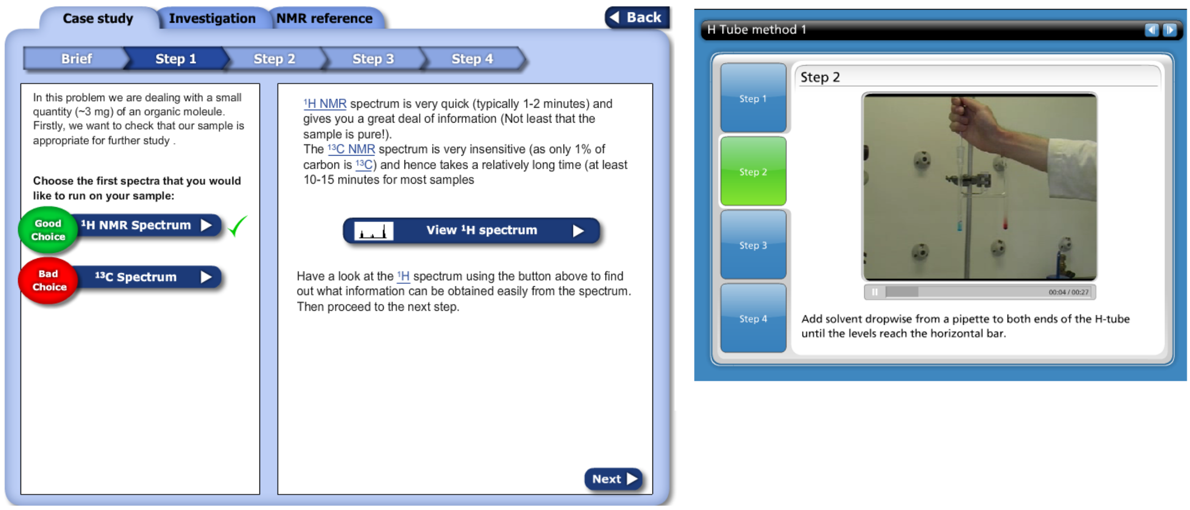


FIGURE E. ADVANCED CONTENT IS ILLUSTRATED WITH INTERACTIVE CASE STUDIES, SUCH AS THE ADVANCED NMR INVESTIGATION (LEFT). WHERE MANIPULATIONS ARE UNIQUE TO AN ADVANCED TECHNIQUE, SUCH AS THE USE OF H TUBES, A VIDEO IS ALSO USED TO HIGHLIGHT THE KEY POINTS AND VISUALISE IMPORTANT STEPS (RIGHT).

How this practice is situated theoretically (the impact of the DLM)

The asynchronous nature of the online content has several advantages over face-to-face workshops or time at the start of the laboratory. It allows laboratory staff to provide individual tailored content to 640 undergraduate students doing 10,760 Chemistry experiments per year. Each student can learn at a pace suitable to them; the content can be revisited as many times (or as seldom) as an individual requires, thereby negating the necessity for all students to complete the pre-lab work over the same time frame, provided it is completed by the deadline.

Pre-lab tests encourage engagement with the online content; which leads to greater focus on the matter in hand and shorter start times in the lab. Online tests allow several opportunities for students to complete the work, giving students the chance to fail, to re-assess their own approach and to improve; it is no longer a 'one shot' process.

The DLM provides automated marking and immediate feedback to the 700 pre-lab tests being conducted each week, dramatically reducing marking workload by an estimated 500 hours per week. While using automated marking of online tests minimises workloads, the online storage of marks maximises efficiency; a single member of staff can check the results of all 100 students entering a lab. Electronic storing of every attempt at the pre-labs also enables effective personalised engagement; from the 100 marks, a member of staff may locate which students have struggled and exactly which questions they failed on, allowing feedback to be tailored to the individual.

Elevating the necessity for pre-lab workshops also minimises timetabling loads, and pre-labs mean students arrive prepared, and immediately begin practical work, without needing to read over the content or consult the demonstrator before they begin. This allows both students and demonstrators to focus on the technique, the theory and the purpose of the particular experiment. The success of this approach was evident in comments on the DLM from the External Evaluator of the Bristol ChemLabS project for the interim report (Warren 2008):

> The most obvious point to an outside observer is the purposeful air and committed attitude of the students at all three levels... The students knew what they were doing and were deeply involved in it... No student at Bristol, when asked what (s)he was doing, replied 'I'm down to here on page 2.'... The DLM (Dynamic Laboratory Manual) is vital to the operation of the labs. *(Warren 2008).*

The delay between students entering the laboratory and beginning practical work in another UK HEI has shown that up to two hours of a three and a half hour session in both the first and second year laboratories was being wasted due to students finding chemicals and glassware, rather than concentrating on the actual science. At Bristol ChemLabS, it was approximately 10-15 minutes before students began, but importantly this time was spent talking about the experiment and setting up kit. The study also commented that the workstations at Bristol ChemLabS were left clean and tidy; every practical contained within the DLM includes a section about how to leave the laboratory. It is clear that the DLM not only improves students' preparation before the class but also the professional attitude to, and preparation for, departure:

> Although the majority of students have left the laboratory before 4.45pm, there did not seem to be an overwhelming feeling that the students had focused all of their energy on how to leave the lab quicker, but how to complete their experiments efficiently. *(Springham, 2012)*

The success of the DLM to support undergraduate students through a programme of practical Chemistry laboratories was measured by several methods. Evidence was gained from both staff and students through face-to-face meetings. Questionnaires utilising Likert-scales (Likert 1932) and allowing open comments, both online and in paper format, were utilised to collect staff and student feedback. Students' marks from laboratories, end of year exams and final year research projects, were collated and compared in order to determine whether the new assessment regimes were adequate and if the Bristol ChemLabS project had an overall effect on the students' final year output. Importantly, all methods were utilised over a period of ten years. Thus a clear picture of the practical skills of undergraduate chemists before the Bristol ChemLabS project was obtained. By carefully targeting select groups of students over the past decade, the critical evaluation from students who had a 'before and after' experience of the project was possible, and allowed contrast with students who had their entire undergraduate career with the support of the Bristol ChemLabS project.

The first evaluation was completed early in the project and took advantage of the unique group of second year students, who had a 'before and after' experience of the CETL project. These students experienced their first year laboratories in the old facilities and their later laboratory classes in the new facilities. While the DLM was not yet in place to support these students, they did experience the enhanced, stand-alone experiments and more focused in-lab assessment schemes. A table of question and the scores the students gave is given in **Table B**.

Table B: View of practical laboratory classes from students who had a 'before and after' experience of the ChemLabS project

Entry	Question	Before ChemLabS	After ChemLabS
1	I looked forward to laboratory sessions	3.20	2.49
2	The laboratory environment provided an excellent teaching environment	3.18	1.78
3	I was prepared in advance of the laboratory	3.47	2.03
4	The assessment used has been a good way to provide feedback	3.22	2.40

Note: Students were asked to score each statement from 1–5; 1 being 'strongly agree', 5 being 'strongly disagree'.

Questionnaire results from undergraduate students who had the full Bristol ChemLabS experience, were compared with those from students who completed their undergraduate laboratory course before the CETL project (Table C).

Table C: Comparing student views of practical laboratory classes before the ChemLabS project

Entry	Question	Students who completed laboratories before ChemLabS	Students who had the full ChemLabS experience
1	This year I was inspired by the chemistry I encountered in thelaboratory	5 % agree / strongly agree	70 % agree / strongly agree
2	This year, staff demonstrators appeared to enjoy demonstrating		76 % agree / strongly agree

Note: Students were asked to score each statement from 1–5; 1 being 'strongly agree', 5 being 'strongly disagree'.

Evidence collected from the group of students who experienced the laboratory course both before and after the project, showed the students appreciated and enjoyed working in new facilities (Table B, entries 1 and 2, respectively). Students identified that they were better prepared for the laboratory (Table B, entry 3) and felt they received better feedback for their work (Table B, entry 4). Students also gave feedback regarding their positive experience of the DLM with comments such as:

Features like the DLM help me know exactly what's going on.

Only 5% of students who were questioned about teaching laboratories before the Bristol ChemLabS project found their experiences 'inspiring' (Table C, entry 1). Of the students who experienced the new laboratories, 70% found the course inspiring and clearly appreciated the progressive nature of the practical experience:

...there was a different emphasis to what we were learning each year, and a greater sense of self-direction and responsibility - this approach kept labs interesting and challenging.

Final year project supervisors were asked to assess how well prepared a student was to complete a research project. This was done in 2005, assessing students who had experienced all their undergraduate laboratories before the Bristol ChemLabS project, and again in 2012, assessing students who had a full Bristol ChemLabS experience. The results are presented for BSc Chemistry students (Figure F), MSci F103 students (Figure G), MSci F104 students (Figure H), MSci F105 students (Figure I) and MSci F107 students (Figure J).

Figure F: Staff responses to the question "BSc students trained in practical Chemistry at Bristol (F100) are well prepared for a research project".

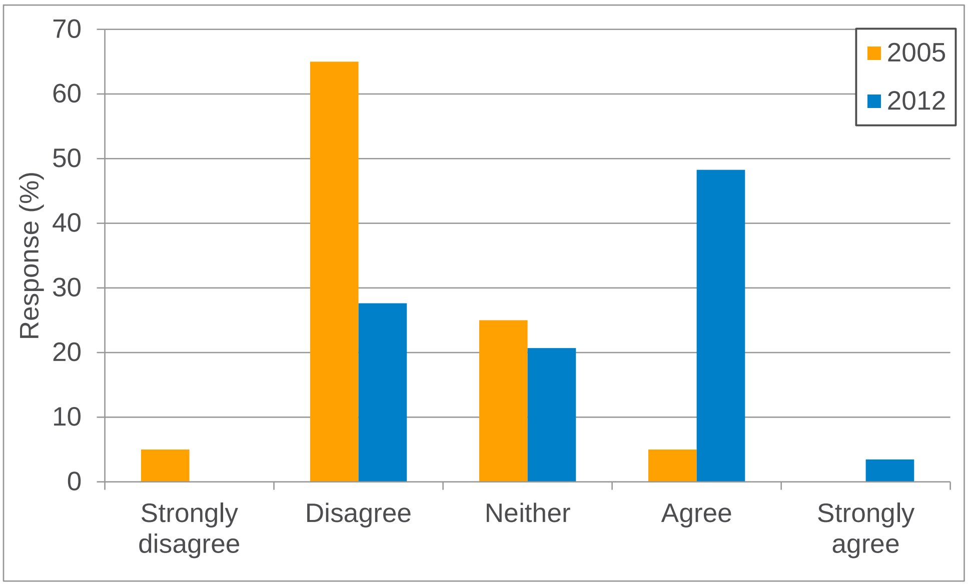


Figure G: Staff responses to the question "MSci students trained in practical chemistry at Bristol (F103) are well prepared for a research project".

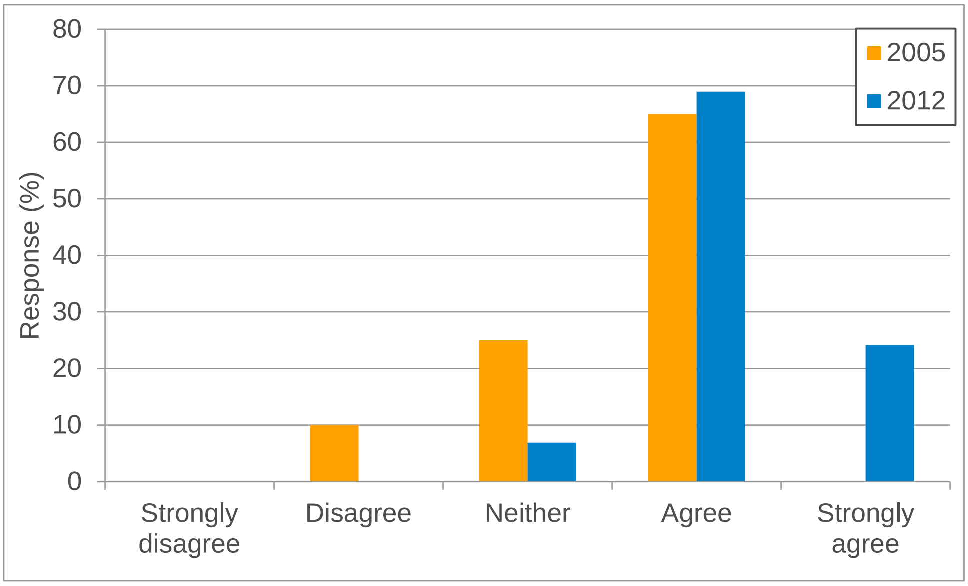


Figure H: Staff responses to the question "MSci students returning from a year in Europe (F104) are well prepared for a research project".

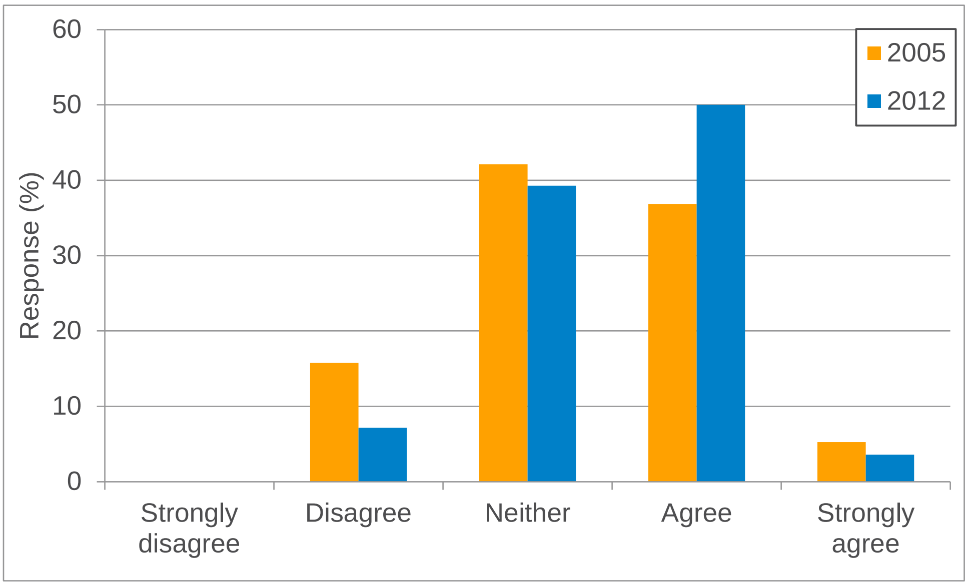


Figure I: Staff responses to the question "MSci students returning from a year in industry (F105) are well prepared for a research project".

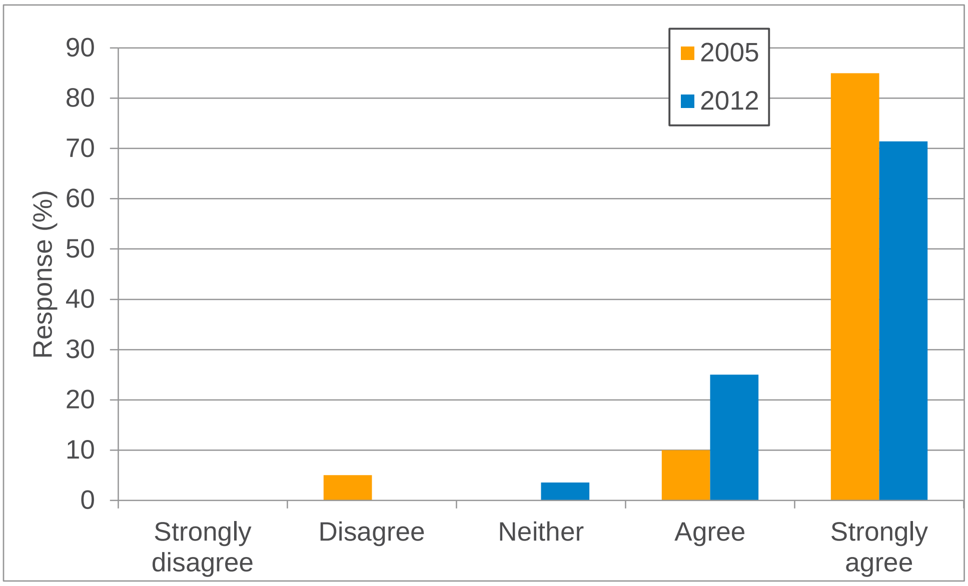
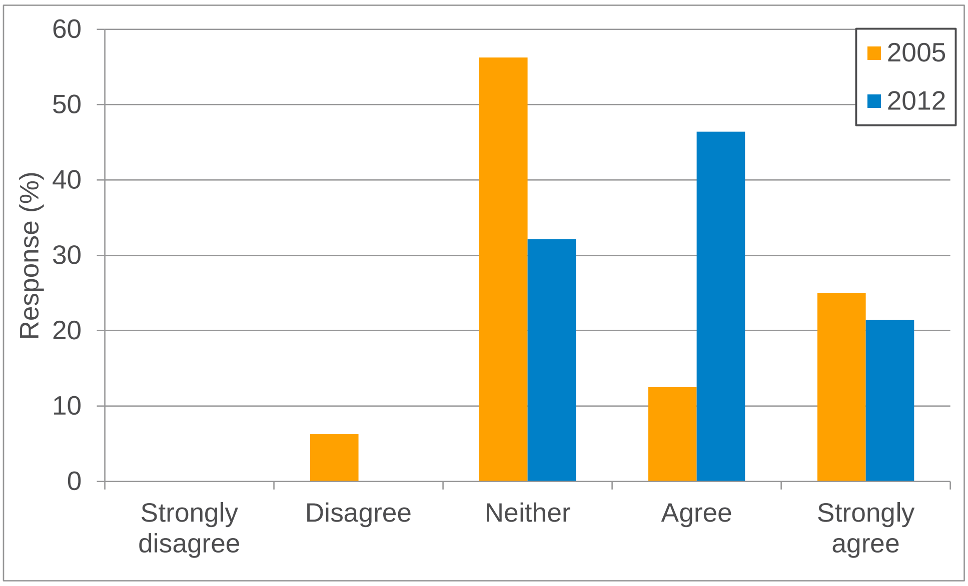


Figure J: Staff responses to the question “MSci students returning from a year in North America (F107) are well prepared for a research project”.



In 2005, the preparedness of final year project students was indicated by project supervisors as poor, for students who had completed the first few years of BSc or in-house trained F103 MSci programmes, (**Figures F** and **G**, respectively), whereas students who had a year out in industry (**Figure I**) were identified as being better prepared for their final year research project. When asked the same questions in November 2012, project supervisors felt both final year BSc and MSci F103 students were well prepared for their research projects. Importantly, the results for the MSci F103 students echoed those for the students who had been out in industry, in part showing the success of the progressive undergraduate practical course design in up-skilling undergraduates for employment in the fields of science and technology.

DLMs as an aid for non-English speaking students

The Ofsted report *Managing support for the attainment of pupils from minority ethnic groups* (2001) identifies, two key factors in which English as an Additional Language (EAL) students can develop their language skills successfully: through performing activities that enable ‘pupils to rehearse and explore the language’ they need; and a focus on the ‘language necessary to complete the task.’ The DLM allows both through the virtual ‘rehearsals’ and via the provision of an equipment and reagent glossaries. The most valued sections of the DLM reported were the video sections of each technique as they provided the opportunity to build mental models for upcoming practical work. The focus on the details of the techniques without the demands or time pressure of the actual laboratory was highlighted. The students reported feeling more confident as they were more familiar with the language associated with the investigation but requested that the text could be read to the students to improve their pronunciation of the English terms.

Feedback on the Chemistry DLM

Two groups of Bristol postgraduates that demonstrated in the teaching laboratories were surveyed; group one were not Bristol undergraduates and group two were and had used the DLM. All group one reported some elements of pre-laboratory practice during their undergraduate years. Indeed at least one of the departments commented on had been influenced by Bristol ChemLabS. These included:

> Safety assessment 'only for some experiments',
>
> Pre- questions on the Blackboard VLE,
>
> Overview of experiments in the form of video (at start of lab),
>
> Pre-lab test for safety online, including chemical structures and reaction schemes (but no mechanisms).
>
> Glassware set up.
>
> Safety quiz with minimum pass mark" to "a sheet of paper to fill in no. of moles, mass etc and 1-3 questions.

When considering whether their own undergraduate university chemistry course would have benefited from access to Bristol's DLM the group were unanimous in agreement. The advantages listed included:

> [having] the opportunity to see the techniques carried out correctly and understand the theory behind them.
>
> …you can watch the videos as many times as needed…
>
> [the DLM] makes sure that each student has an overall idea of the experiment and its risks.

When asked 'do you feel that the majority of U/GS make good use of the DLM for lab work?' Several commented that at the start of term most students will have looked at the DLM/videos but that towards the end of the year students get lazier and relied on demonstrators or think they already knew what to do so didn't bother.

When asked about the advantages to the undergraduate students in their charge, postgraduates commented on the fact that every student has an idea of how to do techniques before starting a lab and that they weren't all following the one or two confident members of the group (as was the postgraduates own experience elsewhere).

> Every student has an overall understanding of the theory and the practical activity.

The demonstrators thought that an advantage to the students was the speed at which they got written feedback and the ease of accessing marks and feedback.

> …they can see what they need to improve next time.

When asked 'As an undergraduate was the DLM of help to you in our practical classes and why?' all Bristol based undergraduates were uniform in agreement that it was.

> Yes, the most help was the videos and techniques and how to conduct them. Knowledge of some very simple procedures was lacking on my part.
>
> Seeing the tech[nique]s in the video gives confidence and understanding.

When asked to comment on whether, in hindsight and with the present position of a demonstrator, that they had 'made best use of the DLM' comments were not always complimentary of the structure:

> Mostly, but hard to know which bits of pre-lab info were the most important and which were just background. Now it's much clearer to me.
>
> No. For a long time I never noticed any of the tabs in the LHS [of the screen] and hence missed quite a bit of information on the techniques.

> Could have used much more but preferred to play with the real thing in the lab than the animations at first.- went back to the DLM when marks came back!

Many of the other comments received here could be regarded as suggestions for improvement of signposting of the DLM, the need for clearer indication of how to use the DLM and perhaps providing a rationale for its use.

The question 'What advantages/disadvantages do you see as a demonstrator of having students used LabSkills?' lead to some interesting discussion. The advantages recognised concerned the fact that students were familiar with equipment they had never used before (and therefore it was easier to demonstrate). Some possible disadvantages included:

> Possible to cheat in pre-labs and therefore don't know what they are doing [when in the labs].
>
> Can remove incentive to actually do background reading- very easy to click tick boxes and not to think.

It was conceded that:

> They get a grounding on the techniques required beforehand, you can then flesh out the idea/point easier, even if they've just clicked through it and seen a picture.

Of considerable interest were the suggestions put forward by these demonstrators, even though they admitted that they were not formally trained in educational theory and that there were some logistical challenges:

A more formal session to be given to first years, during induction, of how to use and navigate the DLM' the first years have a lot of information to process, as well as the thrill of being away at university, that a cursory run through with the expectation that the students will spend time generally looking over the resource well before their first assessed practical is unreasonable. The postgraduates were not considering that university requires students to be more responsible for their own earning than they might have been at school and that all incoming students have access to a version of the DLM from the point of their application to the department.

'Make the primary aim ([expected] educational outcome) of each experiment clearer at the start'. It was felt that some students were confused as to whether the theory, the techniques or getting a high yield was the main aim of the practical procedure.

> Sometimes the mark schemes over emphasise knowledge and <u>not</u> the skills that are meant to be done [learnt]. Make the incentives favour genuinely engaging with experiments.

A response to the request for a 'feedback mechanism on experiments/techniques' to be included was met with surprise when they learnt that there was such a thing already in place that is never used.

The demonstrators commented that

> From a graphical/structured point of view the navigation through pages doesn't seem to flow easily and we can get lost completely miss parts.

It is a valid comment that in the years since the DLM was first conceived there has been considerable progress in the design of interfaces of web-based resources to make them more intuitive. Perhaps the time is approaching for this to be applied to the DLM to give it a face-lift.

The expanding impact of the DLM philosophy

Within Bristol

The DLM techniques manual has extended to include writing skills, plagiarism and data manipulation skills and the pre-lab structure has been adopted in tutorials and workshops. DLMs have been created for Doctoral Training Centres (Nanomaterials and synthetic Chemistry). A taster version of the DLM was set up for prospective students, containing a selection of experiments, tutorials and workshops from across the undergraduate degree programme and it is an integral part of summer schools using the laboratory.

DLMs have been developed (JISC funded; eBiolabs) to support first year Biochemistry practical teaching and for first year Physiology and Pharmacology. In December 2014 a multi-year project to implement DLMs in the Schools of Biological Sciences, Physics and Dentistry at Bristol was completed and it is now the objective at the University of Bristol to roll out DLMs throughout all subjects where practicals are carried out.

Beyond Bristol

One of the original expectations for all the CETLs awarded in 2005 was that they would be sustainable beyond the end of the HEFCE funding. One way that Bristol ChemLabS sought to achieve this was through commercialisation of aspects of the DLM. Therefore, in collaboration with American publisher Cengage Learning Inc., LabSkills modules have been produced to support practical Chemistry skills development in an introductory setting in universities. The Cengage LabSkills products are available on a subscription for universities and individual undergraduate students. Modules including DLM adapted items so far are modules designed for General Chemistry and for Organic Chemistry.

Presently the Cengage version modules that employ Chemistry LabSkills elements are in use in around 40 universities in US, Canada, Spain, Turkey, Ireland and the UK. An estimated 15,000 students per year use these products. In collaboration with secondary school teachers post-16 (UK A level) Labskills products were developed. Each technique section had a brief introduction, an animation to assist the 'inexperienced scientist' to assemble apparatus and a sectioned video with notes at each stage. Interactive notes on the health and safety and multiple choice questions to assess the students understanding of the procedure were added.

> It is important that scarce laboratory time and resources are used to the best effect: practical work needs to be carefully planned so time is used well and genuine enquiry take place. I am impressed by A level LabSkills because it helps prepare the ground so that effective practical work can take place, as well as improving students' confidence and capability. *(Professor Sir John Holman, Former Director National Science Learning Centre).*

> We used LabSkills in preparation for a coursework assessment involving titration and all students found it easy to follow through the materials and complete the test at the end. As a result of this more focused intervention strategy all students were able to score highly on the assessment and unlike previous years none will have to repeat the ordeal. *(Alan Francis, Head of Chemistry, Gordano School, North Somerset, UK).*

Through the Pfizer-Royal Society of Chemistry Discover LabSkills project (Fox 2009) a bespoke version of Chemistry LabSkills was presented to 5.000 secondary schools in the UK on a USB stick. Every higher education institution that trains Science teachers was also given access to an onine version to aid in their training programmes.

Biology LabSkills was also developed to give students confidence and understanding before entering the laboratory to carry out a practical investigation. Modules consider core laboratory competencies covering basic skills such as weighing and dilution, numeracy which includes graphing units of measurement, and analysing data statistics, accuracy and precision. Modules also contain a mixture of safety information where relevant, videos, interactive resources and multiple choice tests.

HEA funded dynamic laboratory techniques manuals (DLTM) for Physics and Biological Sciences (DLTM, 2013)

Building on the success of the DLM and A-Level Chemistry LabSkills, an HEA funded project allowed the construction of pre-lab software to assist transition between schools and first year courses in Physics and Biological Sciences in higher education.

The project allowed a panel of Science experts from secondary schools and higher education institutions (HEIs) from across the UK and elsewhere to produce a list of core practical techniques that are needed in each of these disciplines in the first year of undergraduate degree programme. The DLTMs were constructed using many of the elements of the DLM format. The DLTMs have video clips of practical techniques, health and safety information, and formative and summative assessment.

The rationale behind the project was that laboratory-based skills of incoming first year undergraduates in the Sciences is highly variable; some have had extensive practice in a wide range of practical skills and techniques while others have had no more than those involved in assessed coursework or, for some arriving from overseas barely none at all. The SCORE report (2013) makes a number of recommendations concerning Post-16 secondary school practical their general lack of access to properly equipped laboratories and shortages of equipment and consumables. While these issues are being addressed, students are transitioning from secondary to tertiary education ill-prepared for Science-based practical work. The DLTMs developed here and in the future could be made available to all Post-18 students in allow them to work through basic practical skills in advance of their degree courses.

Both DLTMS were trialed in schools with Post-16 students and with undergraduate students. Both DLTMs are freely available to all UK HEIs to support practical teaching in these subjects. Around 30 UK HEIs have already taken up the resources to add to their own virtual learning environments (VLEs).

How others might adapt or adopt this practice

The impacts of the Bristol ChemLabS' supported pre-laboratory software approach have been seen in other schools within the Faculty of Science, within other Faculties at the University of Bristol, within the British and international university Chemistry departments, within Chemistry teacher training institutions and with pre-university school students in Biology, Physics and Chemistry.

In an ideal scenario, this project should develop into a UK community-based project where groups contribute new elements that are trialled in their own institute, peer assessed and then added to the portfolio. However, for now, interested parties can work with Bristol ChemLabS and obtain a licence to use this material. A Dynamic Laboratory Techniques Manual has been developed which is free to all users that bridges the gap between post-16 and first year work in the Biological and Physical Sciences (DLTM 2014),

Conclusion

The suite of experiments from first to third year allows the undergraduate chemist to progressively develop a practical and transferable skill set essential for success in the employment market. The first year chemists are given the opportunity to focus on developing a set of practical technical skills suitable to a professional chemist. The linkage between these skills is developed in the second year and in the third year the students can then develop the transferable skills of time and project management and independent research successfully, having been given the opportunity to focus on the basics earlier in their undergraduate career.

The online learning resource caters for a diversity of learning styles by providing different ways for students to explore a given topic, through printed or online text, videos, and simulations or photographic explores. In addition students can engage with the content in a manner suitable to them as an individual, attending to an increasing disparity in the pre-university practical experience of first year undergraduates.

Encouraging students to engage with the material before they arrive in the laboratory eliminates the situation where students waste laboratory time reading laboratory scripts or follow laboratory scripts without understanding what the experiment entails. The pre-laboratory tests encourage independent learning from an early stage in an undergraduate career.

A graduated and structured approach to safety preparation allows students to build up skills in risk assessment, becoming more independent and building up to an industry standard approach in their final year research projects.

The assessment activities allow students to demonstrate both practical and communication skills, building throughout their undergraduate career. The assessments approach skills expectations appropriate to the level of study and experience and also assess students through a variety of mechanisms, allowing students with preferences for different learning styles an opportunity to demonstrate their accomplishment and also improve in areas which they are less comfortable.

It is the links between the practical and theory, not the order in which they are experienced, which is essential for learning. The focus on skills works because there is: a sequential building of skills; a removal from lecture ties; a lower level skills focus; a higher level of problem-based learning and independent learning focus. The DLM has shortened laboratory time and enabled in-lab assessment and courses with minimal post-lab assessment. External and postgraduate students can utilise laboratories safely.

Alongside this, improved staff support and feedback is facilitated, as all marks and feedback are collated through the online systems. Thus, an educator can monitor the pre-laboratory theory test results for an entire class but can also utilise the electronic facility to see the specific results for any one student, and tailor response, discussion or support to the individual while monitoring classes *en masse*.

The Bristol ChemLabS project has seen significant success through its outreach activities (Harrison *et al*. 2011a; 2011b; Shaw *et al*. 2010; Shallcross *et al*. 2013a) and this is echoed in the undergraduate laboratories. Since the implementation of new teaching laboratory programmes, which allow students to progressively develop a set of practical skills, staff project supervisors have greater confidence in the abilities of new research undergraduates. This confidence is supported in a rise in final year project marks. That this is due to grade inflation can be negated by comparison of BSc and MSci F103 marks with those for MSci F105 (Figure H). In fact, this comparison shows that the online facilities allowing staff to support students have had significant impact, since greater class size has been accompanied by better project results.

Keeping pace with new technologies and updating content will always be a challenge but where next? A key area is the post-16 to undergraduate transition which builds on the post-16 labskills software. At undergraduate level many areas are of interest, e.g. pre-labs which support group learning and which support problem-based learning. Industrial placement support is another emerging area but there are many more and applying the methodology to other subjects will throw up new challenges.

There is little doubt that the DLM has enhanced student learning in practical Chemistry and stakeholders from industry, schools and HEIs etc. have played a very important role in this.

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Contact us

+44 (0)1904 717500 enquiries@heacademy.ac.uk
Innovation Way, York Science Park, Heslington, York, YO10 5BR
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