INDUCTION DIAMOND LABS - GIVING EVERYONE AN EQUAL STARTING POINT

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ABSTRACT

Multidisciplinary Engineering Education (MEE) is a specialist department at the University of Sheffield, dedicated to the practical teaching of all the University's engineering students. To provide students a hands-on experience, MEE has a unique building (the Diamond) which includes 15 laboratories offering a spectrum of lab activities to approximately 6000 students.
Students arrive at the University from a variety of different backgrounds. To ensure they start their experimental activities with an equal understanding, we provide different "Diamond Induction Labs". During the first two weeks of the first semester, the students learn how to use hand tools, how to solder, understanding how to interpret data and manage uncertainty and how to do it safely. Three key aspects of this delivery method are considered. Firstly, the principles of laboratory practices are transferable to any engineering disciple. This leads to the second, which is that this delivery is done at scale - with minimal resources over 1000 students, perform the activities each year in a short window of time. Thirdly, it allows for teaching the subjects previously done though lectures using instead practical learning. In the "Danger-lab" we ask students to assess measuring the toughness of chocolate using a mini-Charpy impact tester. The danger is increased by asking the students to also dip the chocolate into liquid nitrogen. During the Measurements lab the students determine the variation in measured flow rates between different forms of instrumentation. While the students gain experience in reading instrumentation and recording data, they also develop an understanding of errors and uncertainty and how they propagate across calculations. We have found that students not only have more confidence in approaching learning in different labs, but they have an increased awareness of hazards in a laboratory, and a better understanding as to how to evaluate the uncertainty within practical work.

KEYWORDS

Introductory Labs, Multidisciplinary,
Standards: 4, 5, 6 and 8

INTRODUCTION

About MEE

The Faculty of Engineering at the University of Sheffield offers undergraduate and postgraduate programmes to around 6,700 students in 10 broad disciplines. These are

Mechanical Engineering, Aerospace Engineering, Civil and Structural Engineering, General Engineering, Chemical Engineering, Bioengineering, Materials Science and Engineering, Electronic and Electrical Engineering, Automation and Control System Engineering, and Computer Science and Engineering. All of these programmes must include practical activities, such as experiences in laboratories and workshops, to satisfy the accrediting bodies and because without which an engineering curriculum would be lacking.

All of the disciplines taught within the Faculty have overlaps in their content with other disciplines. For example, Mechanical Engineering, Civil Engineering and Chemical Engineering all include fluid mechanics and Bioengineering, Control system and Electrical Engineering all include electrical circuits. It was therefore decided that, when a new building to house teaching laboratories would be built to accommodate a rise in student numbers, rather than new labs being based on and run by discipline specific programmes (for example, the Mechanical Engineering lab), they would be based types of activity (for example, fluid mechanics) and run by a team independent of a specific department. This model has numerous advantages, including the efficiencies that can be achieved through scaling teaching activities to large cohorts of students.

Multidisciplinary Engineering Education is the teaching only academic department in the Faculty of Engineering with the express remit of designing, delivering and assessing the practical activities for all the programs in the shared laboratory and workshop spaces (standard 7) (Petrova, 2021). The team consists of around 50 employees, including academic, technical and professional services staff. In addition to permanent staff, MEE employs hundreds of Graduate Teaching Assistants (GTAs), on an hourly basis, to provide adequate staff-student ratio in large lab classes. Teaching at scale is core to the ethos and operation of the department and opportunities are constantly sought to identify where learning delivered to one cohort could be valuable to another. These principles of finding commonality and teaching at scale have been the guiding principles in the establishment of the departments “induction labs”.

THE INDUCTION LABS

According to CDIO concept, ‘graduating engineers should be able to conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment’ (Crawley, 2001)

In order to address the CDIO model of teaching in a practical environment, the students need building skills (standard 2) which can facilitate their learning in the core engineering disciplines.

The idea of induction labs delivered at the Diamond is to provide the students starting their undergraduate courses with a common framework knowledge (standard 4). The students starting at the University of Sheffield come from different backgrounds and nationalities. At this point it is difficult to categorise their knowledge from the origin of their education and it is much easier to address certain aspects as not covered.

There are different soft skills (group working, presentation skills, etc.) (Audunsson, 2014), that are addressed across the curriculum in the two years of undergraduate courses, however we want to focus as well on more basic knowledge which can facilitate the students' start of their practical work and help staff to focus more on the core technical, personal and interpersonal skills of the practical teaching.

The setup of the Diamond and the large scale of the facility allows the students to have hands-on experience on different techniques. They can build things, operate, and test them; all activities which to be productive must be safe. As per protocol, Risk Assessments are provided for every practical activity but many students starting their undergraduate course in Sheffield may not be familiar with the process and their application.
Health and Safety is an essential part of practical teaching. However, the theory and implementation of H&S traditionally is taught as a passive transmission of information, in fact writing and reading risk assessments is considered a tedious exercise, however essential.

During this short introductory lab, the students are introduced to the risk assessment by writing one for a simple experiment: breaking chocolate at room temperature and using liquid nitrogen. This activity is more engaging, the students apply the steps of writing a risk assessment for a real experiment that they will have to perform straight after.

The Measurements Lab activity is designed to give the students an understanding of uncertainty and demonstrate what is happening in an industrially relevant engineering context. Engineers design and build things that need to function in the real world, and the real world is full of uncertainty. The measurements Lab also introduces the students to the methods engineers use to work with and overcome uncertainty to allow them to do their job of designing and building things.

The scope of this paper is to underline the importance of our Induction labs in students learning and to demonstrate that considering efficiency from teaching at scale (staff, space, and equipment) does not compromise the expected learning outcomes. Also, our introductory labs are focused on active learning that are more effective to use by engaging students in more problem-solving activities. (Dym, 2005)

We will focus our discussion on two Introductory Labs, which are delivered at the Diamond in the first two weeks of the first semester: Danger Lab (Johnson, 2016) and Measurements Lab.

The Danger Lab

The aim of the Danger Lab is for students to design an experimental protocol to measure the impact fracture toughness of chocolate at room and cryogenic temperatures while understanding the risks and hazards of the process (writing a Risk Assessment).

The students investigate the fracture of chocolate. Chocolate is a convenient material as it breaks relatively easily, it is non-toxic and has properties that vary strongly with temperature.

This lab supports the students in manipulating (breaking chocolate at different temperatures), applying (Risk Assessment concepts), analysing and evaluating ideas (how the toughness of chocolate changes at different temperature) (standard 8).

The Danger Lab is run to class sizes of up to 48 students with a staff student ratio of 8:1, comprising 1 academic member of staff and 2 GTAs. The Danger lab is divided into four parts and is timetabled to last 1.5 hours.

The first part is the Introduction to Health & Safety, where the students are shown examples of hazards and how to evaluate their risk using the risk matrix. During this section, the students are shown how to identify the hazards, deciding who might be harmed and how, evaluating the risk and deciding on precautions. The Introduction to H&S is followed by the Experiment description and demonstration; brief description of how to measure the toughness of materials and a demonstration of how to test the toughness of chocolate at room temperature and liquid nitrogen using mini-impact testers (report the capacity) with appropriate personal protection equipment (PPE).

At this point the students should have enough knowledge to write the Risk Assessment for the experiment. They work in groups (4 students maximum per group), and they are encouraged to write the risk assessment collectively by discussing the various hazards and their risks for the experiment. After writing the Risk Assessment (at least 3 hazards), they must complete an experimental protocol for the procedure of testing chocolate at cryogenic temperature, considering the extra personal protection equipment needed and additional setting up steps according to their Risk Assessment.
At the end the students perform the experiment. At this point the students are trained to perform the experiment and are given chocolate and liquid nitrogen. A brief class discussion follows the compilation of the experiment to analyse the class results.

The Measurements Lab

The measurement lab is designed to teach students to recognize and measure uncertainty in measured data and to provide tactics to both manage and communicate to others uncertainty in an experimental result. This is a foundational skill applicable to all disciples of engineering and underpins experimental work conducted in all the degree programmes taught by the faculty.

Students, working in groups of 4 are provided with a hydraulic bench and a variety of water flow measurement devices that use various physical phenomena as proxies to measure volume flow rate. For example, the Venturi meter measures pressure at two locations using a piezometer and, through a combination of the principles of Pascal's law, continuity and the Bernoulli principle, the volume flow rate can be calculated. These devices are all connected in a hydraulic series to ensure that the flow rate measured by each device is physically identical. The students are then asked to record the measurement and the uncertainty in the raw data collected and consider if, after processing the results, each piece of instrumentation is recording identical results. When there is an inevitable difference in the measurements of each device, students are encouraged to develop a healthy skepticism of the output from any single piece of instrumentation, consider why the results differ from one another and the degree to which uncertainty in the raw and processed results contributes to the discrepancy.

The measurement lab is run to class sizes of up to 80 students with a staff student ratio of 4:1, comprising 1 academic member of staff and 3 GTAs. Session durations are 2 hours. The students usually spend 15 minutes introducing the activity, 45 minutes collecting data and the final hours processing and considering the results. Through many successive repeats of this activity, class management has been honed to an exacting degree. The sessions are typically run 12-15 times in the first week of the University teaching semester, delivering this subject to around 1000 students. Various tactics are employed to scale the delivery, including highly refined printed teaching material that guides students through the work and signposts them to solutions to typically encountered problems, training a pool of graduate teaching assistants (GTAs) to lead and support the sessions, a well produced video to play at the start of the session to introduce the concept of uncertainty and a well designed digital version of the lab available on the VLE to support student that attained or provide an alternative for those students that were unable to attend.

EVALUATION METHOD

In order to evaluate the gain in efficiency from teaching subjects at scale, data on the resources required to deliver the induction labs has been gathered and compared to similar lab classes delivered by MEE (Table 1). Resources consider of note for this analysis are

1. Academic staff and Graduate Teaching Assistant (GTA) contact time during timetables sessions (in hours).
2. Time required for academic staff to train GTAs to deliver the session (in hours).
3. The one off time required to develop the teaching material, including preparation of the lab sheets, planning the session and providing supporting material on the VLE (in hours).
4. The technician time required to set up and take down the lab equipment for the session (in hours)
5. Timetabling efficiency, defined as hours of contact divided by the setup and take down time.

Timetabling efficiency is a proxy to quantify the space use cost of delivering an activity. Space charges, typically charged by a university to academic departments to cover the infrastructure costs such as heating, lighting, cleaning and security, vary between different institutions and can be considerable for city centre campuses. Our definition of timetable efficiency is an attempt to analyse the utilization of space. We run the Induction Labs at full lab capacity (80 students for the Measurements Lab and 48 students for the Danger Lab). However, the full capacity does not only consider an acceptable parameter of space but also allows the students to perform an activity safely and be involved directly with the process and equipment.

For comparison with the danger and measurement induction labs, the resources listed above have also been calculated for two other, non-induction labs run by MEE. The “Ductile to Brittle Transition Temperature (DBBT)” lab has been chosen to compare to the Danger lab and the “Calibration of a flow measurement device” lab, run to 1st year mechanical engineering has been chosen to compare to the measurement lab. These labs have been selected because they are similar experiments to that used in the Introductory labs and are, ostensibly, the same activities lasting the same duration. When taught as induction labs, they are designed for students to meet transferable learning outcomes to a broad range of engineering programmes and when run as non-induction labs they teach subjects specific knowledge to a limited range of engineering programmes. We do not have any data to compare with a situation without Induction labs as we have always run them since opening the Diamond. The percentage difference in the investment of resources, compared to the induction labs, has been calculated based on the per student numbers.

Accessing data in large organizations can be challenging. The centralisation of lab teaching to be delivered at scale justifies the investment of effort to create efficient systems and processes. For example, when GTA allocation of teaching duties is done at a small scale in departments, it is done in a fairly ad hoc way with little process management, as the task is too small to justify optimizing. MEE, in contrast, employs so many GTAs that a streamline system has had to be developed. In addition, MEE’s funding model of contributions from all other engineering departments places it under comparatively larger scrutiny than the income generating departments. As such, a system to plan, manage and audit all teaching activities has been developed. One such system is referred to as your “directory of activities”. As well as providing its primary function, the directory of activities provides a resource of data to be harvested for teaching evaluations such as that presented here.

RESULTS

Table 1. Comparison of resources for teaching at scale

	Danger Lab	Measurement Lab	DBTT	Calibration Lab
Number of students	1368	820	213	194
Total contact time *(hours)*	61.5	30	12.5	8
GTA contact time *(hours)*	140	94	47.5	16
Staff contact time *(hours)*	123	60	25	16
GTA contact time *(hours/student)*	0.10	0.11	0.22 (220%)	0.082 (-134%)
Staff contact time *(hours/student)*	0.090	0.073	0.012 (13%)	0.082 (112%)
Staff training time *(hours)*	2	2	2	2
GTA training time *(hours)*	2	16	3	4
Staff training time *(hours/student)*	0.0015	0.002	0.009 (600%)	0.010 (500%)
GTA training time *(hours/student)*	0.0015	0.020	0.014 (933%)	0.021 (105%)
Development time *(hours)*	10	18	15	8
Development time *(hours/student)*	0.007	0.02	0.07 (1000%)	0.04 (200%)
Technician time *(hours)*	12	2	50	4
Technician time *(hours/student)*	0.0088	0.0024	0.23 (2590%)	0.021 (875%)
Timetabling efficiency	74%	94%	20%	60%

DISCUSSION

Work loading of staff is of significant concern in the UK HE sectors, and one of the primary causes for recent industrial actions by unions. Finding innovative methodologies to reduce staffing reduces staff time input without compromising the student experience is of paramount importance. As expected, the result shows that by scaling teaching, in most cases the amount of contact time required by staff and GTAs was reduced. The effects are less noticeable in the required training and development time. While more teaching would typically require more contact, activities that need to be completed once regardless of the amount of teaching become much more efficient when scaled up. The most dramatic results are seen in the technical and space resources. When equipment needs to be set up and taken down between different activities, staff are required, and the equipment/room cannot be used for other purposes. By running many sessions sequentially, this wasted can be substantially reduced.

The initial development of these intro labs was a lengthy and trial and error process. We had to address the impact on staff and facilities to deliver a back-to-back activity to such an impressive number of students in a short period of time. In retrospect, it has been a successful journey. At the start of each academic year, we need to train the new GTAs and staff which is still more effective compared to the non-induction labs training.

We have not considered in the comparison the turnaround time. For the Intro labs, which run during the first two weeks of the first semester, the turnaround time is practically zero because we run lots of the same lab back to back in the same space. In comparison the core labs across the semester are scattered due to timetable constraints and the same lab can be delivered once a week across different weeks.

For a number of reasons, also the equipment and consumables costs have not been included as part of the evaluation. Primarily, this due to the difficulty in determining to what extent lab equipment contributes to individual activities. Many pieces of equipment found in laboratories are considered part of the standard facilities and so are present regardless of the activities conducted. Consumables costs tend to be negligible in comparison to staffing costs. However, as is quantitatively shown with other resources considered in the results, teaching at scale encourages the reduction of costs for equipment and consumables. If a single use sample costs £10, this is of little concern if it is used by 10 students. If it is used by 1,000 students, the investment of intellectual effort in considering an alternative sample or teaching method could be used to fractionally reduce the unit price.

The labs do not have a formal assessment during or after the session, the students have to turn up and get involved. This setup makes the lab more relaxed and fun, however it may be considered of little importance without any form of assessment. In practice, the students are observed when they undertake the labs - so a form of formative direct assessment takes place, considered more advantageous in a practical environment (Reiss, 2015).

The aim of the Danger Lab is for students to understand how to write the RA and how to use it. The aim of the Measurements lab is for students to recognize and measure uncertainty in measured data. As a result, the Intro Labs are not directly linked to the specific module outcomes. They are more generic and basic skills which will be indirectly assessed downstream at some point during the practical sessions in the context of a broad range of engineering programmes.

The Intro Labs are flexible, practically you can take the danger lab anywhere. We have used this lab for different contexts, such as staff training or outreach activities (mostly schools). The Measurements lab is restricted to the equipment located in the Fluids Lab in the Diamond at the moment, however the same concepts and calculations can be transferred to any other measurement equipment.

We have demonstrated that we can run induction labs in an efficient and scalable way without compromising students learning. This has a positive effect on staff load and space usage. The students learning outcomes cannot be directly and numerically proved as we do not have purposely a summative assessment for these labs. The aim of the Induction labs is to make the students aware of how to work safely and how to analyse measurements and uncertainty. We have ‘checking points’ during the rest of the semester, which allows us to remind the students of what they have done during the Induction labs and apply the knowledge to the core labs. Almost each lab activity involves hazards, risks, measurements, and errors. The students must use the Risk Assessments provided to answer the prelab quizzes based on the hazards and risks before the lab session. While taking measurements the students must do it correctly to a specific accuracy of the equipment used and consider the uncertainty involved and process any discrepancies.

CONCLUSIONS AND FURTHER WORK

In conclusion the Diamond Intro Labs have been a success from a point of view of student participation and engagement, staff workload and delivery efficiency (timetable efficiency in Table 1). These labs are fun in an instructive way, giving the students an equal starting point regarding safety and measurements techniques, easy to set up and provide training for.

We want to do more in providing students with opportunities to acquire skills that are not directly connected with module outcomes and do it without the pressure of pass or fail. During core labs the students are more focused on the results and the learning outcomes of an experiment and do not have a perception of the path they have used to get there.

We in MEE are looking to implement a set of practical skills opportunities spread across all the academic year to shift the focus from core knowledge (theoretical) and concentrate more on practical skills (basic CAD, robotics-Turtlebot, intro to E&C, basic python), which can be used in conjunction during their course but also for working future experience.

Also, it is worth mentioning that these labs are free to the public and anyone interested in developing any of these skills for their courses.

FINANCIAL SUPPORT ACKNOWLEDGEMENTS

The authors received no financial support for this work.

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BIOGRAPHICAL INFORMATION

Joanna Bates holds a degree in Industrial Chemistry from the University of Bologna, and a PhD degree in Catalytic Processes from the University of Liverpool. She joined the Materials Science and Engineering Department at the University of Sheffield in 2011, after completing her PDRA at the EPSRC National Service for Electron Paramagnetic Resonance Spectroscopy at the University of Manchester. She joined the MEE in 2015 initially as Technical Team Leader, helping to set up the new department and she has been promoted to University Teacher since 2017. She teaches and develops Materials Science and Engineering labs to UG and PGT students across the Faculty of Engineering.

Andrew Garrard is Professor of Engineering Education and Head of the Department of Multidisciplinary Engineering Education. He holds a degree in Mechanical Engineering from the University of Sheffield, where he also conducted his PhD research into regenerative fuel cell systems for energy storage. In 2008 he took up a lectureship at Sheffield Hallam University. In 2009, he was promoted to senior lecturer and was responsible for leading the thermofluids teaching group. He rejoined the University of Sheffield as part of Multidisciplinary Engineering Education in 2015, helping to set up the new department in the role of Departmental Director of Learning and Teaching followed by Deputy Head of Department. He took the position of HoD of Multidisciplinary Engineering Education in 2022.

Edward Browncross is a software developer with over 10 years' experience. He has worked as a software engineer working on cutting-edge remote labs at other HE institutions (the Open University and the University of Bradford) as well as spending 4 years as a lead engineer, building modern, cloud-native systems with one of the world's largest software consultancies. He joined the University of Sheffield in 2022. He supports MEE and the wider Engineering Faculty in delivering best-in-class teaching quality, student support and staff wellbeing by building innovative digital solutions to the problems staff and students encounter day-to-day. This includes everything from workflow automation and data warehousing to virtual reality and remote labs.

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