2023

Reflections On Engineering Home Lab Kit Use In A Post Pandemic Environment

Joel ROSS
Faculty of Engineering, University Of Bristol, United Kingdom, joel.ross@bristol.ac.uk

Sean LANCASTLE
Faculty of Engineering, University Of Bristol, United Kingdom, sean.lancastle@bristol.ac.uk

Becky SELWYN
Faculty of Engineering, University Of Bristol, United Kingdom, r.selwyn@bristol.ac.uk

See next page for additional authors

Authors

Joel ROSS, Sean LANCASTLE, Becky SELWYN, Greg RICHARDS, Sarah JONES, Dominic HARDMAN, and James SAUNDERS

REFLECTIONS ON ENGINEERING HOME LAB KIT USE IN A POST PANDEMIC ENVIRONMENT

JM Ross[1]
University of Bristol
Bristol, UK
ORCID: 0009-0002-9594-4014

SA Lancastle
University of Bristol
Bristol, UK

RK Selwyn
University of Bristol
Bristol, UK
ORCID: 0000-0001-9664-4318

G Richards
University of Bristol
Bristol, UK

S Jones
University of Bristol
Bristol, UK

D Hardman
University of Bristol
Bristol, UK

J Saunders
University of Bristol
Bristol, UK

Conference Key Areas: *Innovative Teaching and Learning Methods*
Keywords: *Home Lab Kits, Laboratory Practice, Engineering Experimentation*

ABSTRACT

Laboratory experience in engineering significantly impacts upon how students view their courses. Whilst there may be nostalgic memories of what this offered the educator on their own route through further education, it is often far from the modern

[1] *Corresponding Author*
JM Ross
joel.ross@bristol.ac.uk

reality: time bound, pre-configured, minimal student agency over input variables, and something of a data grab and dash.

Home Lab Kits (HLK), one of the innovations whose use was accelerated as a COVID-19 mitigation, have provided some long-term improvements in the educational lab experience of undergraduate engineering students in the School Civil, Aerospace, and Mechanical Engineering (CAME) at the University of Bristol. The HLKs provide an experience that allows for: independent play and exploration, development of extracurricular experimentation, and time to problem solve and learn from mistakes. This paper reports on both the educator experience and the student voice for a large common team-taught engineering lab unit delivered to ~550 students.

Students report that they have “used [HLKs] for a number of [their] own projects”, that they are a “great way to get people excited about what we're actually learning about” and “made [them] feel like an engineer”.

Whilst HLKs provide for less prescriptive laboratory classes, they can also lead to students being worried about less structured problem solving. However, combined with well-designed taught elements, they can produce an exciting buzz of real-time investigation and collaboration with students.

1 INTRODUCTION

1.1 Background

As is becoming the catchphrase of the decade, the Higher Education (HE) sector is going through a time of unprecedented turmoil and change with COVID 19 and the rise of freely / cheaply available generative artificial intelligence language engines potentially revolutionising the HE environment . Whilst these changes may have accelerated moves towards digital learning, the laboratory experience and practice of engineering hands-on-skills is difficult to replicate in a simulated environment. For instance, whilst the use of pre- and post-tests and virtual lab activities have resulted in more frequent engagement with the learning materials and no detriment to assessment scores, virtual labs do not necessarily help embed curiosity .

Home Lab Kits allow students to carry out practical work in their own homes, and became increasingly popular with both staff and students during the COVID-19 pandemic . A selection of simple parts and equipment is delivered to students, who are then required to use the kit to complete an activity at home, similar to one they may have previously completed on campus. This allows learning outcomes to be satisfied, practical skills to be developed, as well as encouraging a more investigative and open-ended approach than traditional ‘black box’ on campus experiments.

1.2 CAME School Home Lab Kits

The common first-year laboratory unit known as Engineering by Investigation (EbI), delivers a laboratory experience to ~550 students per year. The unit is common to Aerospace, Civil, and Mechanical Engineering, as well as Engineering Design courses, and provides a Home Lab Kit (HLK) to each student. Whilst faculty support was initially driven by the need to facilitate learning in COVID-19 restricted context, it had been the teaching team’s desire to move in this direction for some time. A key concern of the teaching team was that laboratory offerings were evolving into a somewhat turnkey experience as a result of time and space constraints. The HLKs were designed to facilitate exploration, where problems with a degree of open-endedness could be proposed for students to solve and explore using techniques taught in the accompanying lecture series, while still satisfying the learning outcomes associated with practical activities. The contents of these kits are extensive, and an example is illustrated in Fig. 1.

Fig. 1. 2022-23 HLK

A summary of the contents is provided below:

- Selection of mixed resistors, capacitors, and diodes
- Various Integrated Circuits (ICs) including 555 timers, op-amps, logic gates, voltage regulator
- LEDs
- Raspberry Pi Pico microcontroller
- Breadboard
- Jumper wires and wire cutters
- Multimeter
- Drawing equipment
- Miscellaneous experimental equipment: strain gauged aluminium, measuring cylinders, syringes, safety glasses, measuring tape, steel rule, vernier callipers (analogue), to name a few.

The total number of different components was ~88 with a total part count of 260 items. Whilst certain items were selected to facilitate pre-identified laboratory tasks a large number were also incorporated for students' personal projects and future use throughout the degree programme. Indeed, two further second-year labs have been facilitated by the additional components in the kits.

1.3 Learning outcomes and lab activities

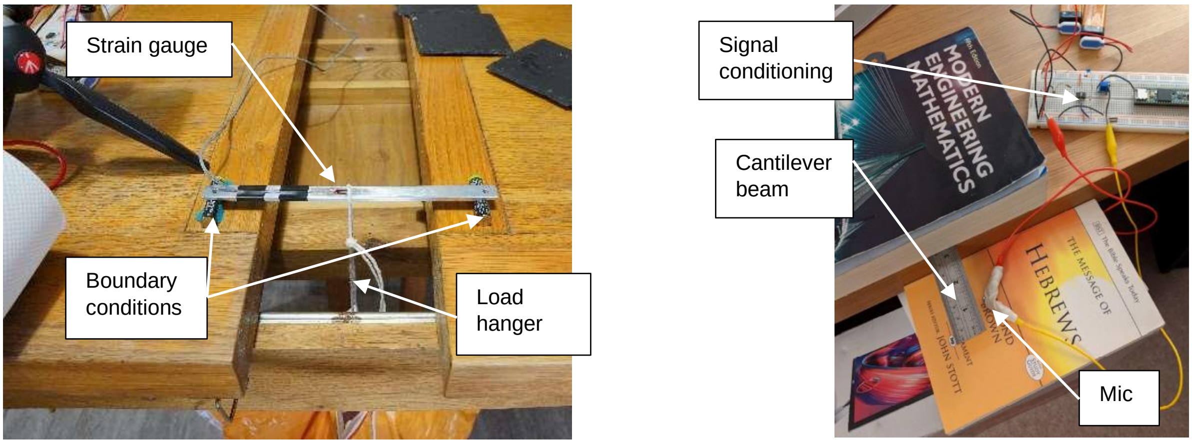
This section highlights some of the key laboratories that are facilitated with the HLKs in the context of the intended learning outcomes of the unit. Whilst the full Intended

Learning Outcomes (ILOs) are publicly available they can broadly be categorised into 4 core elements:

- Engage in required Health and Safety processes such as risk assessments.
- Develop Python coding skills to evaluate numerical data and present output appropriately.
- Use electronic principles to develop basic signal conditioning, acquire signals, select appropriate sensors recognising the impact on error, accuracy, and resolution.
- Structure a written report, including appropriate use of tables and figures, to present a coherent story.

There are four at-home labs:

1. Thermodynamics lab (formative) – evaluate the specific heat capacity of water (using a stopwatch and a measuring cylinder) and the performance of your kettle.
2. Simple bending lab (formative) – using basic hand tools (vernier callipers, steel rule, tape measure) evaluate the empirical results collected against that of Bernoulli-Euler Beam Theory.
3. Strain lab (formative) – using a provided flat strain-gauged aluminium bar, build a Wheatstone bridge with associated amplifier, implement a shunt calibration, and evaluate the empirical strain against that predicted by analytical theory. Student example shown in Fig. 2 (a)
4. Dynamics lab (summative) – using the microcontroller to acquire data, amplify a microphone output to measure the frequency content of a cantilever beam (steel rule). With the observed fundamental frequency, estimate the Young's Modulus of the material. Student example shown in Fig. 2 (b)



(a) (b)

Fig. 2. Examples from student reports, (a) Strain lab, (b) Dynamics lab

Additionally, there is one on campus lab that provides access to research laboratory equipment.

1.4 Scope of this practice paper

While Home Lab Kits were commonly provided during the pandemic, there is little literature around their continued use post-pandemic now that many institutions have returned to a business-as-usual approach to labs. In this paper, we aim to report our experience of embedding use of home lab kits into a 1st year practical skills unit as a potential new best practice. We report student experiences of using the kits, as well as staff reflections, and hope that by sharing our experiences others will be inspired to introduce or continue using home lab kits.

2 METHODOLOGY

The evaluation of the HLK intervention has been two-fold. Firstly, a broad overview of the cohort experience was collected through a survey of students enrolled in the unit in 2022/23 (ethics approval was given by the Faculty of Engineering Research Ethics Committee at the University of Bristol – ref. 14061). Secondly, the teaching team (the authors) have reflected on the use of HLKs since 2020/21 through informal discussions.

A survey was designed to collect user feedback from students, and included questions on both the practical experience of using the HLKs (Questions 1-3,9) and the logistics of accessing support while using them (Questions 4-8). Questions were also included to provided general feedback on user experience (Questions 10-12).

The delivery of these kits to cohorts of ~550 students represents a substantial financial investment at approximately £200 per kit, so their use and adoption are crucial to ensuring good value and return. The main survey questions are shown in Table 1 (the participant consent questions have been omitted from this table).

Table 1. Survey questions

#	Question text	Response options
1	The Home Laboratory Kit was easy to use?	Five-point scale: strongly disagree, disagree, neutral, agree, strongly agree
2	The kit helped me engage with the content of the units for which it was designed?	
3	The kits have helped me in other units and/or my own projects?	
4	The supporting material (e.g. videos/manuals) was helpful	
5	I was able to access the Laboratory Kit BB page through the QR Code	
6	The Inventory of Parts on Blackboard was helpful	
7	Did any components break whilst using the Home Laboratory Kit?	Free text
8	Are there components included in the kit that are not needed?	
9	Are there any components that should be added?	
10	What did you like the most about your kit?	
11	What did you like the least?	
12	Do you have any other suggestions or comments on how we could improve the Home Laboratory Kit?	

3 RESULTS AND ANALYSIS

3.1 Five-point scale responses

The survey had 90 responses from the student population, ~16% of the total cohort. Whilst this was lower than hoped as a proportion of students, the total number of responses was still high enough to draw some useful conclusions. The five-point scale output is shown in Fig. 3, with a broadly positive outcome across all questions.

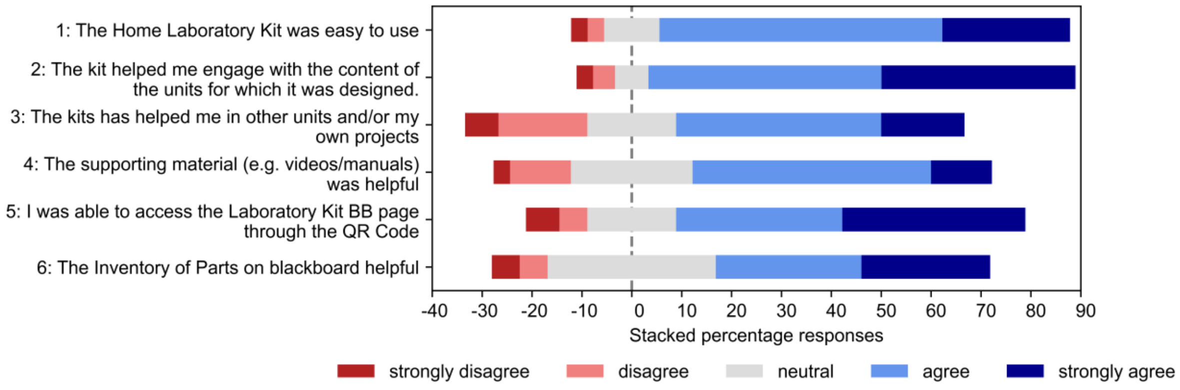


Fig. 3. Summary of Likert scale responses

The survey results indicate that the kits perform exceptionally well in fulfilling their original design purpose of supporting the core unit. Questions 1 and 2 show 82% (93% inc. neutral) and 86% (92% inc neutral) response rate towards agree and strongly agree for the kits being 'easy to use' and 'helped me engage with the content of the units for which it was designed' respectfully. This provides good evidence that the kits were performing their intended task well. With the other questions less narrowly focused on the kit's ability to perform its intended purpose the breadth of response increases. Question 3, for instance, is extremely dependent on the student's own interests – students who identify as 'hobbyists' are more likely to use the HLK contents in their own personal projects, whereas students who are less confident or interested may be less likely to explore using the HLKs for other purposes. However, even in this category 58% of respondents suggested it was helpful outside of the immediate unit. While on-campus labs can have some benefits, including exposure to research/industry-grade equipment, , they are also usually limited in scope to allow a large number of students to complete the lab during specific timetabled sessions. The positive responses to Q3 is suggests that the value of the kits extends beyond the planned activities which is harder to achieve with a conventional lab approach.

3.2 Free text responses

A large number of the free text responses from the students were associated with specifics of components (questions 8 and 9) which would not add to the discourse of this paper; thus, these have not been included, but have been used by the teaching team while reviewing the HLK contents for 2023/24. Responses to the other questions have been categorised by theme within each question, and the categories and number of responses are shown in Table 2.

Table 2. Categorisation of free text responses from N=90. Note that the total number of responses for each question does not necessarily sum to 90 as the questions were not compulsory, so some respondents did not answer all questions.

Q7: Did any components break whilst using the Home Laboratory Kit?	
Coding category	**Count**
Strain gauges	12
LEDs	6

Miscellaneous	6
Q10: What did you like the most about your kit?	
Coding category	**Count**
General positive comments	35
Use for own projects / creativity / at home	22
Variety of components	15
Tools supplied	13
Portability	11
Raspberry Pico Pi	9
Q11: What did you like the least?	
Coding category	**Count**
Box size	17
Variety of components	9
Difficulty repacking	6
Miscellaneous	23
Q12: Do you have any other suggestions or comments on how we could improve the Home Laboratory Kit?	
Coding category	**Count**
Provide smaller sub containers for carrying parts to university	5
Label individual components	5
Provide printed components list not web QR code	4
Make the kit smaller	4
Would like a stronger box	2
Would prefer traditional on campus labs	2

A key outcome from Q7 was the relatively high number of failures of the strain-gauged aluminium bars (13% of respondents reported this problem) and LEDs (7%). The strain-gauged bars were required for one of the formative labs, and the LEDs were used during the first circuit building taught session. Although students have reported problems with these components, teachers noticed that most often failures were due to user error, typically a fault in the circuit either leading to the LED being over-powered, or the strain gauge not being powered at all or being incorrectly amplified. This has reinforced the need for the teaching team to provide clear and appropriately pitched support for novices when building and troubleshooting circuits. Troubleshooting circuits has been observed to fundamentally challenge students taking the unit, where the tacit skill of methodical fault finding is lacking, and changes to the way this is taught are being incorporated into the unit for 2023/24.

The responses to Q10 help to unpack some of the reasons for the previous positive feedback in the five-point scale responses. While 39% of responses contained generic positive comments, 24% specifically mentioned the opportunities the kits provided for extracurricular activities associated with creativity, as well as the reduced time constraints when working at home. There were further tacit benefits, as illustrated by students reporting that "it made [them] feel like an engineer," "Being able to conduct real experiments at home," "I've used it for a number of my own projects so far and can see this continuing and being added to by myself," and "I have [components] that I can keep once lectures finish so I can continue to make things." These responses hint at the transformative change that this approach has compared to the previous one. While in two cases, students directly referenced a desire for more on-campus labs, there was no evidence of a cohort-wide desire for a significant change to the HLK approach. In fact, many of the responses referenced benefits from the HLKs which would be unachievable with traditional laboratories, supporting the decision to continue using HLKs post-pandemic.

4 AUTHOR REFLECTIONS

The authors of this paper are all involved in designing and delivering the HLK activities reported in this paper, and have drawn together their reflections on the benefits and disadvantages of HLK usage.

Amidst the complexities of today's Higher Education sector, the kits have provided a highly scalable solution to delivering engineering labs that can be easily sequenced with other taught content. For instance, due to timetabling constraints, on campus labs used to be delivered either significantly before or after a science topic was taught. HLKs are not impacted by these constraints, and have provided new opportunities to deliver laboratory experiences at appropriate timings compared to the underpinning engineering science taught elsewhere.

An additional challenge of home labs is the changing prior experience of our intake. While previous generations were perhaps more likely to have spent time disassembling and repairing engineering artefacts like radios, bikes, cars, and desktop PCs, today's society frequently uses sealed devices making this tinkering more difficult. Anecdotally, staff delivering labs have noticed a decrease in both confidence and ability of students undertaking practical tasks, leaving our students potentially less comfortable with aspects of home exploration, but potentially in more need of it. This discomfort was particularly evident when using early iterations of the HLKs in a fully online delivery mode. Adding in-person group activities using HLKs as part of the taught sessions on the unit seems to have reduced this problem. Careful design of home labs to gradually increase the complexity of activities throughout the year has also allowed students to familiarise themselves with each level before moving on to the next.

One further concern of the teaching team was the inability of HLKs to expose students to industry standard equipment. To combat this issue, one ‘traditional’ on campus lab is offered, with a focus on students predicting and estimating their results before conducting the experiment. The focus on prediction is to ensure that the key skill of critically evaluating data in real time during collection is practiced. This encourages students to consider the quality of data collected before leaving the laboratory, whereas when using HLKs students are not constrained in this way and often repeat an experiment excessively without considering whether their results are sensible.

5 CONCLUSIONS

This paper reflects on the ongoing use of HLKs in a 1st year lab unit. It provides student centred evidence that the use of HLKs for the development of experimental skills and curiosity has had a positive impact. The vast majority of respondents (82

%) suggested the HLKs were easy to use suggesting the kits were appropriately pitched for 1st years. In general, HLKs have been well received, and students are not demanding a return to the previous days of solely providing on campus labs. Staff reflections also confirm this positive impact, especially when considering the demands of providing a scalable solution for practical activities. However, careful design of supportive in-person activities and scaffolded at-home activities are required to ensure students are not overwhelmed when developing their practical skills in isolation.

6 ACKNOWLEDGMENTS

The authors would like to acknowledge the outstanding professional and technical service provision provided by the Faculty of Engineering at the University of Bristol. Lastly, special thanks to James Saunders, who developed additional optional HLK activities and provided permission to use his report photos as examples of HLKs in action.

REFERENCES

Aliane, Nourdine, Rafael Vargas Pastor, and Gonzalo Vivas Mariscal. "Limitations of Remote Laboratories in Control Engineering Education." *International Journal of Online and Biomedical Engineering (iJOE)* 6, no. 1 (01/24 2010): pp. 31-33. https://doi.org/10.3991/ijoe.v6i1.1131. https://online-journals.org/index.php/i-joe/article/view/1131.

Chen, L., P. Chen, and Z. Lin. "Artificial Intelligence in Education: A Review." *IEEE Access* 8 (2020): 75264-78. https://doi.org/10.1109/ACCESS.2020.2988510.

Cossu, Remo, I. Awidi, and J. Nagy. "Can We Use Online Technology to Rejig the Traditional Laboratory Experience to Improve Student Engagement?". *Higher Education Pedagogies* 7, no. 1 (2022/12/31 2022): 1-19. https://doi.org/10.1080/23752696.2022.2068155. https://doi.org/10.1080/23752696.2022.2068155.

Howard, Daniel, and Mariel Meier. "Meeting Laboratory Course Learning Goals Remotely Via Custom Home Experiment Kits." *The Physics Teacher* 59, no. 6 (2021): 404-09. https://doi.org/10.1119/5.0021600. https://doi.org/10.1119/5.0021600.

Treve, Mark. "What Covid-19 Has Introduced into Education: Challenges Facing Higher Education Institutions (Heis)." *Higher Education Pedagogies* 6, no. 1 (2021/01/01 2021): 212-27. https://doi.org/10.1080/23752696.2021.1951616. https://doi.org/10.1080/23752696.2021.1951616.

Youssef, Farid F., Junette Mohan, Elaine M. Davis, and Melford John. "Home-Based Physiology Labs in the Time of Covid-19 Prove Popular with Medical Students." *Advances in Physiology Education* 45, no. 4 (2021): 709-14. https://doi.org/10.1152/advan.00048.2021. https://journals.physiology.org/doi/abs/10.1152/advan.00048.2021.