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One kit to rule them all: designing take home lab kits at programme level

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***Abstract*—Many educators use take home kits to provide practical hands-on activities to their students. There are clear benefits, including increasing opportunities for practical learning, meeting a range of student learning styles, and maximising inclusivity.**

It is common to use take home lab kits to illustrate individual experiments or even for whole modules, but it is rare to work across modules to create a single curated set of parts for use over an entire programme, including modules that would not be obviously connected with the kit contents. By giving responsibility for practical engineering education to a dedicated team, practical learning outcomes can be analysed for overlap and complementary activities. A single set of equipment can then be specified and certified safe for take home operations, providing both time and cost efficiencies for staff.

We present the design of a take home kit for use across multiple modules of a first year undergraduate programme in electrical and electronic engineering. There are clear benefits from crafting a developmental practical programme across modules, using just one home lab kit. We describe the design stages of the kit specification, the alignment with learning outcomes, and important considerations for inclusive teaching practice.

***Index Terms*—Electronics engineering education**

I. INTRODUCTION

To enhance practical experience in higher education, take home kits have been used for many years. For distance learning institutions which offer limited access to lab time, small kits of equipment can be the only option for hands-on experience of scientific concepts. For primarily in-person institutions, take home lab kits can be used to increase practical experience by overcoming limits on the available lab time, while also allowing students to take control of their own learning and to focus on the course elements that matter to them.

However, kits are often designed for a single module, or perhaps even a single activity. While this allows an in-depth study into particular topics, it does not help students to develop practical skills through their whole course, and may involve a steep learning curve in the method of learning using a kit. A better approach would be to design a kit at programme level, cutting across several modules and building successive activities upon each other. Even if the underlying course content is vastly different, the practical skills necessary to explore or apply the concepts can be closely related.

Using the unique oversight of all practical engineering activities by the department of Multidisciplinary Engineering Education at the University of Sheffield, this paper presents our design for a take home kit designed at programme level. By integrating all of the activities together into a linked programme, activities that would normally not be related through their inherent content can contribute to a coherent practical developmental pathway.

II. PRIOR WORK

Take home kits have been used to enhance practical education across a range of settings for many years. It is most common to use take home kits for electronics and control courses, due to the ease of creating low cost and safe collections of equipment (in contrast to chemical or mechanical kits).

An example electronics and control home lab for a dedicated purpose uses a ”helicopter” with two fans providing thrust and freedom of movement across three axes for a single control systems module [1]. While the authors report strong student engagement and cost savings from a take home kit approach compared to fixed lab equipment, they discuss the need for simple software approaches and the challenges of providing real-time support to learners.

A take home kit was also used exclusively for a mechatronics and robotics course within a wider programme of ICT education [2]. Even though the work takes a long term strategic programme view over ICT topics, the take home kit use is limited to one small module rather than designed for full course programme use.

An interdisciplinary course used a series of lab kits based around the Arduino platform in [3]. By creating an openly available set of kit designs, a scalable platform is created for a range of experiments. This work showed good scaffolding development through the course, increasing the complexity of the software and hardware constructed, but this was limited to a single course rather than an entire programme.

For a larger budget per kit, a full suite of experimental equipment could be sent to each student using a dedicated case [4]. This kit design proposed communications links over the internet to allow real time support for remote learners. Although not mentioned in [4], this kit design has the potential to be used for many different experiments across an entire course.

An attempt to replace in-lab equipment with a bespoke home lab kit in [5] found that the intended learning outcomes of a practical course could be delivered just as effectively with take home kits. A scaffolded approach developing skills over five activities was used, but all activities related to the content of a single course module.

A system designed for pre-university experiments in [6] created an "I-Virtual" lab experience using specialist data acquisition hardware. The functionality allowed a range of phenomena to be observed, from simple Ohm's Law verification to diode I-V characterisations. Such a system demonstrates that a single kit could be used for multiple learning outcomes, although further work is required to align learning outcomes.

An attempt is made in [7] to construct a single lab kit to cover a range of topics. The design targets a basic electronics course, which tackles subjects across analogue and digital electronics. However there is no mention of wider topics in an engineering programme such as system level design or fundamental device physics.

In this work we seek to build on the recommendations of prior work (simplifying software requirements on students, and providing real-time support where possible), to create a new programme level kit design that feeds into multiple modules, including system design, device physics and programming.

III. Practical activities within the programme structure

The first year Electrical and Electronic Engineering (EEE) programme at the University of Sheffield takes a standard modular approach, with separate modules for devices, circuits, maths, programming and general skills. Practical activities are integrated closely into each of the modules, and are timetabled to be delivered close to the relevant didactic content i.e. students learn the theory about a particular component or device in a lecture or video, then in the same or following week, perform a relevant experiment to apply this new knowledge.

While each practical activity is designed with distinct learning outcomes, this modular approach does not naturally lead to a cohesive programme of practical work for the students. Without careful planning, successive lab activities from different modules may include duplication, missing prerequisites, or just gaps in the students' practical capabilities. The only way to resolve this is to holistically consider all of the practical activities together, even if they are contained within separate modules or based around very different underlying content.

Key to developing the is identifying the learning outcomes to be delivered from a practical activity, further than just supporting the didactic content. By focusing on different aspects of practical skill in each activity (e.g. experimental data recording, experimental design, instrumentation etc.), it is easier to identify new models for delivering the same intended learning outcomes. This approach was shown to be very effective when rapidly moving learning online during the covid-19 pandemic [8], although it is just as applicable outside times of crisis.

Table I shows just some of the Take Home Kit activities in the context of supporting practical and simulation work. The table is presented in approximate chronological order, since some activities are prerequisites for future tasks. Module names are also given here as an approximate guide to the core theoretical content that the activity supports.

TABLE I
Practical activities centred around the Take Home Kits

Module	Activity	Delivery
General Skills	Analogue and Digital Inputs and Outputs	Take Home Kit
General Skills	Building a Voltmeter	Take Home Kit
Electronic Devices	Measuring LED Band-gap voltages	Take Home Kit
System Design Analysis	Solar Panel Electrical Characterisation (IV)	Take Home Kit
General Skills	Advanced Arduino	Take Home Kit
System Design Analysis	Solar Maximum Power Point Tracking	Take Hone Kit
General Skills	Circuit Simulation	Simulation
Electric Circuits	H-bridge motor control	Take Home Kit
System Design Analysis	Closed loop motor speed control	Take Home Kit
Electronic Devices	BJT Amplifiers	Simulation
General Skills	Audio Amplifier and DAC	Take Home Kit

There are clear pathways between the activities, where the expected learning outcomes for earlier activities lead to the subsequent tasks. If students are required to focus on new content at the same time as learning new practical techniques or skills, the effectiveness of the overall learning is greatly reduced. The design of these lab pathways is such that prior practical skills can be repeated in future labs, so that new content can be introduced alongside the practical exercise.

Examples of these pathways include:

- An initial activity on digital input and output is followed by creating a voltmeter. Students learn how to use of microprocessors for analogue voltage measurement, and then interpret their measurements. The voltmeter can be used to measure the voltage drop across LEDs, and observe that different colour LEDs have different band-gap voltages - combining skills in microprocessor code and circuit design with fundamental device physics.
- Using the voltmeter constructed earlier, and a range of resistors, the voltage/current graph for a solar cell can be plotted. This leads to a further activity to automate maximum power point operation for the solar cell under different lighting conditions. The underlying device physics of a solar cell are thus combined with a control systems algorithm, alongside analogue input and output from a microcontroller.
- A simulation activity allows students to explore a simple bipolar junction transistor amplifier, using a single transistor. In the final take home kit activity, a push-pull output stage is used to create an amplifier capable of driving a small speaker. This expands on previous BJT concepts to allow application of the prior learning from

simulation, showing students how simulation can be used before practical circuit construction.

These examples of programme level collaboration allow students to develop skills from one module and apply them in other contexts. The core topics of each practical activity remain aligned with the module content, but the practical activities directly relate and form pre-requisites to each other. Up to 6 clear learning outcomes are provided for each practical activity (e.g. ”Use a microprocessor to construct a simple voltmeter” and ”Name some factors that affect the precision of voltmeter readings”). These are decoupled from learning outcomes that relate only to the core course theoretical content, so that the practical pathway can be independently developed.

It is notable that this kit is used for practical skills training in modules other than circuit construction and analysis (which is the focus of most electronics take home lab kits, as studied in the Prior Work discussion). The System Design Analysis module is used to introduce EEE students to wider considerations of engineering solutions e.g. heat management, encasing and recycling. A module on Electronic Devices includes the underlying semiconductor physics behind diodes and transistors. Even though the experiments that can be performed all require some basic circuit construction, the design of the kit and experiments still allow the illustration and hands-on experience of relevant topics (e.g. LED bandgaps and microprocessor control of a multiple input and output system).

IV. Take Home Kit Contents

Once an entire programme is constructed around a single take home kit, all required components can be combined into a single package for students to receive via a postal delivery or collection from the campus. Fig. 1 shows a selection of the take home kit contents. It is a deliberate feature that all components are combined together rather than separated into week-by-week bags - this reduces excess packaging, requires reuse of components between activities (reducing costs), and also exposes students to the very real challenge of component identification.

TABLE II
Take home kit contents list

Arduino Uno	USB Cable
Solar Panel	Resistors and potentiometers
DC Motor	Capacitors
Speaker	Diodes
DAC (12-bit using SPI interface)	LEDs (multiple colours including white)
Op-amp (4 devices in single DIP chip)	Pushbutton switches
Motor driver (Full H-bridge)	Breadboard and single core wires
Transistors (BJT)	Small screwdriver

To meet cost requirements in particular, it was not possible to include any form of data acquisition device or miniaturised oscilloscope. This meant that activities had to be designed to create instrumentation using the kit itself (e.g. the voltmeter activity early in the programme), or that they had to be designed without requiring external instruments. This presented a challenge in creating activities to meet learning outcomes in experimental data recording and analysis.

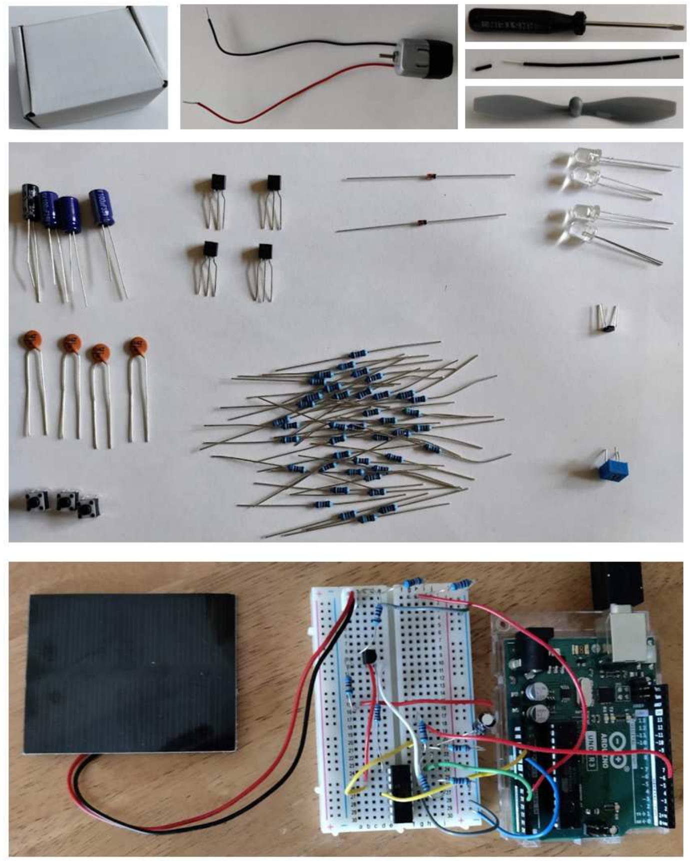

Fig. 1. A selection of the contents included in the kit. Including from top, the cardboard storage box, motor with pre-soldered wires and tape, screwdrivers, wire and a propellor. Centre, the passive components, showing the scale of the challenge for first year students to identify components. Bottom, a completed activity to build a solar panel maximum power point tracker.

To generate meaningful numerical datasets despite a lack of measurement equipment, the final construction project required students to create a digital-to-analog converter followed by a simple push-pull amplifier, working at audio frequencies. Students could then use any mobile device of their own with a microphone, and a freely downloadable app, to characterise the system frequency response. This allows data gathering for the construction of meaningful graphs (e.g. frequency vs. amplitude) without requiring the students to connect unchecked and potentially faulty circuits to their own devices, risking damage.

The example of a complex audio device for a final project can only be successful because the learning can focus on the new content. Prior learning outcomes of transistor functions, digital input and output from a microcontroller, and fast Fourier transforms for frequency analysis have all been taught elsewhere in the programme, using the same take home lab kit.

By working across modules and designing a practical pathway across a programme, a complex capstone project can still be successfully delivered remotely.

V. Staff Feedback

The preparation of kits for in-person teaching consumes a considerable amount of time and staffing. It is preferable to move as much of this work outside of the teaching semester as possible, so that the teaching technicians can spend more time actively teaching in the lab with students. By moving to a single take home lab kit for use throughout the teaching year, the kits can be prepared once during the summer period. There is then no need for kit preparatory work through the term, since students can be given their kits once at the start of the academic year.

However, the responsibility for kit preparation for each activity then lies with students. This means students must remember to bring their kits to every session - only a few spares are maintained within the laboratory. Generally this responsibility shift has not been problematic, although it required multiple and frequent reminders to ensure that students brought their kits to the lab on days that it was required.

The take home kits are the responsibility of a single teaching team, which enables rapid response and real time support. Weekly sessions using an online platform were used to provide real time opportunities for feedback. However, these sessions were underutilised. Far more queries were received by email rather than during the timetabled drop-in online sessions. Although some queries from students are poorly worded and contain little evidence of their problem (photos, screenshots), it is perhaps an implicit learning outcome for the students to learn how to communicate data with experts. After providing photos or videos, all student problems could be remotely solved to their satisfaction.

Additional work is required to consider all aspects of component usage before sending out the items to students. Early in the project, it was decided that students would not have access to soldering irons, or wire cutters or strippers. The decision was made primarily on safety grounds for unsupervised use, and secondly on cost-saving measures. This meant that all components must have wires soldered to them before adding them to the kits, and any multicore wire must have tinned ends for breadboard use. Additional precautions were taken such as using insulation tape to relieve strain on fragile solder joints - resoldering breakages might be very easy in the laboratory but not so feasible remotely! While these might sound like obvious precautions to take, only through immaculate kit planning could the activities be delivered at scale (to 100 students) without fault.

VI. Student Feedback

Following each remotely delivered practical activity, students were invited to complete a feedback questionnaire. Free text comments on a range of activities delivered using take home kits were thematically classified and clustered. The comments presented here exclusively relate to activities delivered using a take home kit format.

Flexibility in how and when to learn was a common theme, with comments such as: ”Really loved having a take home kit, and being able to program outside of normal lab hours.” and ”I find this module quite difficult to get my head around so the ability for me to go through this slowly at my own pace has really given me to opportunity to completely understand the content covered in this session.”

An important recurring theme is the provision of adequate/effective support, where the students have access to instant, actionable feedback. Students commented ”The main problem is when someone has a tiny mistake that can be solved by the [staff] in a matter of seconds if they actually saw the circuit. With everything being online, it is easy to miss something if you’re working alone. A tiny mistake can cost you hours to find.” Frequent, effective feedback is paramount for the successful delivery of the remote teaching approaches. Another student agreed, saying ”It was different, interesting, engaging, difficult to get help outside of the set activity times”.

A particular theme in students approaching activities like this is requiring independence to be able to engage fully with the required practical activities. A student approaching one of the first independent construction activities made the comment: ”I don’t want to sound too negative; I just think that I, probably along with some others, don’t have the independent working skills to engage with something large-scale and independent yet. Hopefully, over the coming months, I will develop these skills and begin to work more effectively.” A further answer ”being able to build something on your own was fun” is always a pleasing review of any practical activity, although it highlights that students felt that they were tackling these challenges alone, despite all of the assistance available.

These comments support the case for a holistically managed labs programme, which develops student skills between modules. If a single module presented students with a take home kit for the first time and expected students to fully engage, an entire unit of learning might be affected. However, by taking a view across all modules and gradually building skills, students gain confidence as well as practical skills. This gradual approach is enhanced by initially running activities for skill development without assessment while students are still ”learning how to learn” when using a remote kit approach.

In answer to the prompt ”What did you like about the course?” the answer from a student ”Using a lot of past taught techniques” reinforces that our design encouraged students to see the links backwards and forwards between the activities, even if they are not always signposted.

VII. Inclusivity

Before commencing this project, a full analysis was taken of the inclusivity impacts of moving previously in-person activities to take home kit delivery. It is imperative that practical teaching is available to all students equally, with no barriers to participation. Some important inclusivity findings for future educators from both our initial analysis of inclusivity challenges, and observations from our practice, are summarised here.

- Some students work from home in environments with children. The inclusion of small parts in these kits could present a major hazard for young children, or even pets. The kit should therefore be supplied in a robust, reusable box so that no hazards could be accessed between sessions. High quality cardboard boxes were found to be suitable, provided they can be repeatedly closed securely.
- A significant minority students have some degree of colourblindness. The kits were initially prepared with a selection of required through-hole resistors, and a colour code chart for them to be identified. A pragmatic solution for students unable to use the colour code was to suggest a suitable multimeter that they could purchase locally, and they could submit the receipts for reimbursement of the cost of this essential equipment (even if the course budget could not stretch to a multimeter for every student).
- Inclusivity also includes barriers of social and economic status, where students may not have the resources at home to engage with the course. In our experience all students could find access to basic office equipment (paper, scissors etc.) and did not need to ask for assistance from programme leaders, despite a dedicated system in place for this. A larger potential issue is access to IT equipment, however this is a wider issue than just for practical work (it is needed for online video learning and assessment etc), and university-wide initiatives to provide equipment for those in genuine need was sufficient to meet the demands of this course.
- Overall our inclusivity assessment showed that take home kits would be more inclusive than traditional fixed time in-lab sessions. The flexibility offered by working on lab activities in students' own time and homes allowed them to work around family, work and faith commitments, as well as adapting to different learning styles. However this has to be matched by flexibility in the staff support - sometimes out-of-hours real-time assistance through video calls or emails is required to resolve problems quickly and effectively. This in turn requires support for the staff concerned, with flexibility in their working hours over each week, to avoid their burnout and overwork.

VIII. Long-term Impact

Given the clear success of this project, we have retained a take home kit structure for the 2021-22 practical activities programme, alongside in-person teaching. Access to laboratories is now freely available (following Covid-19 guidance), so students can work on the same activities in person during timetabled teaching sessions, while taking their kits home between sessions to work on the practical activities at their leisure.

To further enhance the programme level design of the kits, students returning to the campus will have additional sessions in a manufacturing workshop to manufacture a base plate and mounts for some of the components, shown in Fig 2. This allows students even from an EEE specialism to experience 3D printing, laser cutting and basic workshop tooling. By integrating the workshop activity with the kit, a cohesive activity is constructed which maintains engagement, even though students might not always see the immediate relevance to their course in first year. Only through a programme level view of take home kit design can such successful engagement be achieved.

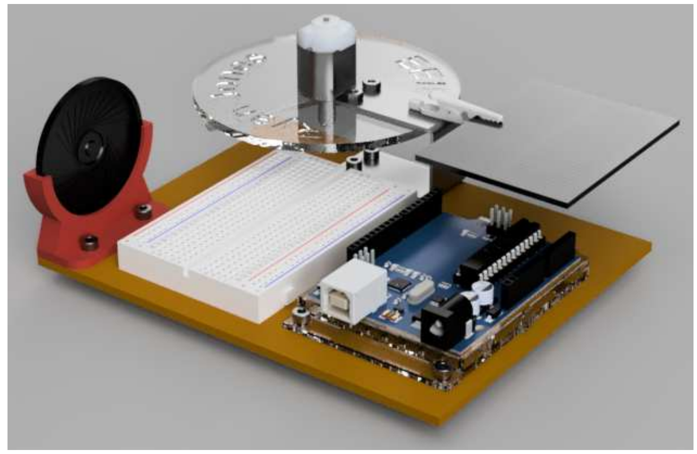

Fig. 2. Rendered design of the base and component mounts, that students manufacture for themselves. Includes laser cut wood and plastic (after adapting relevant CAD designs) and a 3D printed speaker holder.

IX. Conclusion

By taking a holistic programme-level overview of take home kit practical activities, students can transfer practical skills between modules and use a single collection of parts. Even if the core content of a practical activity supports fundamental content for a specific module, there are transferable practical skills that can be developed across the course as a whole.

The take home kit project was efficient for staff to deliver by shifting staff preparation time into holiday periods, allowing more flexibility in delivery. There are some important design considerations for the kits from an inclusivity perspective, although overall take home kits can be a more inclusive teaching delivery method than in-person lab sessions.

Even though the development of a take home lab kit was initially in direct response to the Covid-19 pandemic, it will remain a key part of the degree programme. By directly linking take home labs to in-person experiences such as manufacturing workshop skills, a consistent student experience is maintained across the course, strengthening students' multidisciplinary practical abilities.

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