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A Take Home Laboratory to Support Teaching Electronics: Instructors Perspectives and Technical Revisions

Tom O'Mahony
Department of Electrical & Electronic Engineering, Munster Technological University, Cork, Ireland (tom.omahony@mtu.ie) ORCID 0000-0002-0658-5797

Martin Hill
Department of Electrical & Electronic Engineering, Munster Technological University, Cork, Ireland (Martin.Hill@mtu.ie) ORCID 0000-0002-5018-1992

Annie Duffy
Department of Electrical & Electronic Engineering, Munster Technological University, Cork, Ireland (Annie.Duffy@mtu.ie)

Michael Murray,
Department of Electrical & Electronic Engineering, Munster Technological University, Cork, Ireland (Michael.Murray@mtu.ie)

Raul Onet
Basis of Electronics Department, Technical University of Cluj-Napoca, Cluj-Napoca, Romania (Raul.ONET@bel.utcluj.ro) ORCID 0000-0003-0891-2015

Marius Neag
Basis of Electronics Department, Technical University of Cluj-Napoca, Cluj-Napoca, Romania (Marius.Neag@bel.utcluj.ro)

Luis de la Torre Cubillo
Computer Science and Automatic Control Department, Universidad Nacional de Educación a Distancia (UNED), Spain (ldelatorre@dia.uned.es) ORCID 0000-0002-9648-9597

Dao Zhou
AAU Energy, Aalborg Universitet, Denmark (zda@energy.aau.dk) ORCID 0000-0001-9531-4309

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Abstract

In comparison with in-person, simulation and remote laboratories, take-home laboratories have received little attention within engineering education. This article reports on qualitative data that was collected from eight academic staff members to evaluate the effectiveness of take-home laboratories. The laboratories consisted of a range of embedded development platforms along with a bespoke Home Electronics Laboratory Platform (HELP) that was designed to support the learning of analog and digital electronics in the early years of our programme. The findings indicate that take-home laboratories can foster the development of independent learners and enhance troubleshooting skills. Participants also identified that supporting students in their troubleshooting activity was particularly challenging in a remote environment. While the findings should particularly resonate with on-line and distance learning Electronic Engineering programs we also suggest implications for in-person laboratory practices.

Introduction

Within the discipline of engineering, the dominant approaches to laboratory practice have been in-person, simulation-based or remote laboratories. Existing research has explored ways of doing each along with their relative advantages and limitations (Corter et al. 2011; Brinson 2015). An alternative to these three modes of delivery is the take-home laboratory which has received scant attention within the engineering education research literature. A take-home laboratory (also called a distance laboratory) can be defined as an educational laboratory where students perform hands-on experiments with physical devices in their own homes[1]. Learning support is provided from a distance. Compared with in-person laboratories, an essential difference is that with take-home laboratories, students are physically situated in an environment that is remote from the university. An essential difference compared with virtual, simulated or on-line laboratories is that students experiment with real, physical devices as part of the take-home laboratory. While both remote and take-home laboratories utilize physical devices, in remote laboratories students experiment with physical equipment via the internet, whereas with take-home laboratories the equipment is located in the student's own home.

In this article we aim to highlight the potential of the take-home mode of laboratory delivery. A key part of the response of the Dept. of Electrical & Electronic Eng., at Munster Technological University (MTU), to the COVID-19 pandemic was to send to students a range of equipment including a bespoke low-cost Home Electronics Laboratory Platform (HELP). The HELP platform is open-source and so can be easily replicated within other institutions, or purchased for a low cost. It can be used to enable learners develop a rich understanding of core concepts associated with Electronic and Embedded Systems Engineering. Currently, the authors are collaborating on an ERASMUS+ EU project which is developing new versions of HELP, along with a community of practice to support its use and adoption across different modes of learning (distance and in-person). In this article, we briefly describe the HELP kit and evaluate the usefulness and impact of the take-home laboratory from the instructor perspective. We draw on our experiences to discuss some implications for current and future practice.

Related literature tends to rely heavily on student-satisfaction surveys to evidence the impact of the take-home laboratory (Oliver and Haim 2009; Stark et al. 2013; Kommu, Uttarkar, and Kanchi 2014; Popovic et al. 2020). In contrast, our evaluation draws on qualitative data from staff. The primary contribution, therefore, is a richer understanding of the potential of take-home laboratories. This is especially important for on-line and distance learning environments, where take-home laboratories are a means of embedding practical learning experiences. Within these environments, take-home laboratories can increase student enrolment, help motivate learners and develop practical skills (Kennepohl 2017). This richer understanding also impacts more traditional in-person environments as take-home laboratories can be used to realise project-based experiences (Onet et al. 2022) which have been shown to positively impact learning and enhance student retention (Vesikivi et al. 2020).

1. A Review of Some Related Literature

1.1. In-person Laboratories

A strong argument in favour of in-person laboratories is that students need to develop practical skills (NRC 2006). Additional arguments are that students should experience applying theory to practice, experience designing and conducting experiments and experience dealing with the unexpected data that is likely to arise in real experiments (Nickerson et al. 2007). However, these laboratories can be expensive to commission, operate and maintain (Magin and Kanapathipillai 2000). Furthermore, students may spend a lot of time setting-up and

[1] We are assuming a broad interpretation of the word "home" to mean the physical space that the student currently resides in and could be rented accommodation.

dismantling components and restricted access provides limited opportunities for personalized learning (Nickerson et al. 2007).

1.2. Virtual, Simulated and Remote Laboratories

Existing research has explored the effectiveness of simulated (virtual or web-based) and remote laboratories. Brinson's (2015) review analysed 56 articles to empirically evaluate the effectiveness of these various laboratory modes. Laboratory effectiveness was evaluated in relation to six generic laboratory learning outcomes: Knowledge & Understanding; Inquiry Skills; Practical Skills; Perception; Analytical Skills; Social and Scientific Communications. The overall finding is that in 89% of the studies, student learning outcome achievement is equal or higher in simulated or remote laboratories compared with in-person laboratories. This enhanced performance did not vary significantly with the type of laboratory learning outcome. These findings are broadly consistent with earlier reviews by Ma and Nickerson (2006) and Corter et al. (2011). The emerging conclusion would appear to be that designing effective laboratories (Bright et al. 2008) is perhaps more significant than whether the laboratory is in-person, simulated or remote.

1.3. Take-Home Laboratories

As a response to COVID-19 the majority of engineering departments appear to have transitioned to simulation and remote laboratories, with little consideration given to the potential of take-home laboratories (Dunai et al., 2021; Fergus et al., 2020; Vergara et al., 2022). This is especially apparent from the reviews by Gamage et al. (2020) and Tukiar & Kassim (2021) in which there is no mention of take-home laboratories. The evidence from the limited published literature is that take-home laboratories have been developed to support a variety of subject areas including mechatronics (Stark et al. 2013), fluid mechanics (Meng et al. 2019), mechanical engineering (Schajer 2022), control systems (Jouaneh and Palm 2013), embedded systems (Kommu, Uttarkar, and Kanchi 2014), digital electronics (Oliver and Haim 2009) and communications (Popovic et al. 2020). In the majority, the focus is on describing the kit and then describing some typical experiments to outline its use (Schajer 2022; Popovic et al. 2020; Meng et al. 2019).

1.4. Impact of Take-Home Laboratories

In the studies that do explore impact, student questionnaires are the most commonly adopted instrument (Kommu, Uttarkar, and Kanchi 2014; Popovic et al. 2020; Stark et al. 2013; Oliver and Haim 2009). The findings show high levels of student satisfaction. For example, in the study by Kommu, Uttarkar, and Kanchi (2014) students rated satisfaction with the take-home lab kit 4.8 (out of 5) and satisfaction with the hands on experience and mini-project 4.5 (out of 5). Similarily, satisfaction with the curriculum was rated 4.68, and ease of use of the take-home kit 4.53 (both out of 5) in the study by Stark et al. (2013). Oliver and Haim (2009) also present some comments from students who noted that with the take-home approach "you have more time to complete and understand each assignment" and "it gives students a bit of responsibility." A few studies have explored the potential of take-home laboratories to meet the 13 ABET engineering laboratory learning objectives – Instrumentation, Models, Experimentation, Data Analysis, Design, Learn from Failure, Creativity, Psychomotor, Safety, Communication, Teamwork, Ethics and Sensory Awareness (Feisel and Rosa 2005). In their study, Stark et al. (2013) asked students to rate their confidence in each of these outcomes before and after completing the course. Students reported noteworthy gains in Instrumentation, Models, Experimentation, Design and Communication but no improvement or a slight decline in Learn from Failure, Creativity and Teamwork. While the overall trend is positive towards take-home laboratories, these various evaluations are limited by the fact that evaluations mostly consist of simple descriptive statistics that do not establish statistical significance and no control group or comparative data is provided.

In contrast, the research by Bishop et al. (2021) compares a range of different laboratory delivery modes (in-person, take-home, simulation and remote) that were adopted by the department during COVID-19. The different modes were adopted by different modules based on the best fit for the specific needs of that module. These different modes were assessed through a student questionnaire with both closed and open-ended questions. It represents a relatively large study with 254 student responses in total. While the in-person labs were rated highest by students (the authors do note that the novelty of this mode during COVID-19 could be impacting on this rating), take-home laboratories were generally rated higher than simulation and remote laboratories. The article suggested that take-home laboratories might be more useful in advanced courses (second-year on) as first year students need a lot of support to use and apply the equipment and were less successful at managing their time. Another notable exception is the study by Oliver and Haim (2009) who report that when they transitioned to the take-home experience, 12% more students achieved a final grade that exceeded 50%.

1.5. Summary and Contribution

Comparatively speaking, take-home laboratories have not really featured in the engineering education literature. The instances that have been reported in the literature tend to be isolated subjects (Oliver and Haim 2009; Popovic et al. 2020) rather than strategic decisions made at the Department, Faculty or University level. Evaluations of these initiatives are somewhat limited via the student satisfaction surveys typically employed. In contrast then, the main contribution of this article is to document the experiences of eight academic staff with take-home laboratories, who prior to this experience would have exclusively supported in-person laboratories. The significance of this research is that it contributes to our understanding of the merits, limitations, and possibilities of take-home laboratories relative to in-person engineering laboratories. Knowing this we are better positioned to judge if, when and how take-home laboratories should be used to support student learning. Secondly, the article provides a technical summary of an open-source take-home laboratory, called Home Electronics Laboratory Platform (HELP) that can be used to enable learners develop a rich understanding of core concepts associated with Electronic and Embedded Systems Engineering.

2. Research Method

2.1. Action Research

The research approach adopted in this study was based on action research. The purpose of pedagogical action research is to "systematically investigate one's own teaching/learning facilitation practice with the dual aim of improving that practice and contributing to theoretical knowledge in order to benefit student learning" (Norton, 2018, p. 59). Typically action research consists of cycles of planning, acting, evaluating and reflecting (Kember 2000). This particular study adopted the cycle illustrated by Figure 1.

Figure 1: Action research cycle adopted (Norton 2018)

2.2. Identify Problem

As an Engineering Department at Munster Technological University (MTU) we emphasise the development of practical electronic engineering skills. COVID-19 and the possibility of Remote Emergency Teaching continuing for a number of semesters posed a real problem. How could we continue to develop student's practical skills outside of the physical laboratory?

2.3. Research Solution

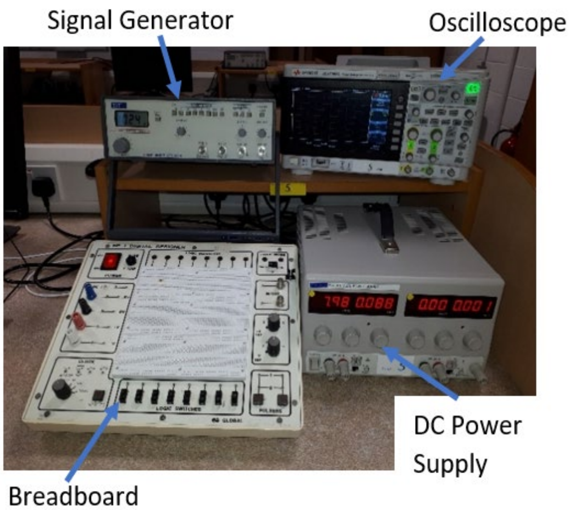

Figure 2: Minimal requirements for traditional electronics laboratory

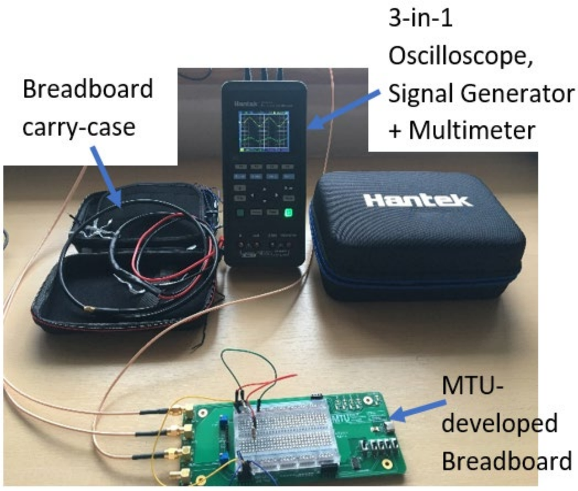

Figure 3: Take-home electronics laboratory kit

The proposed solution was to investigate whether it was feasible to develop a low-cost equivalent of the traditional laboratory that could be sent home to students. Minimal requirements for a traditional electronics laboratory, illustrated by Figure 2, include a power supply, oscilloscope, signal generator, multimeter and breadboard. The breadboard is a device for building temporary circuits. A power supply can be used to configure fixed input signals (e.g. 5V, 0.5 ampere) while the signal generator can be used to apply varying input signals e.g. a sine-wave. The multimeter (not shown in Figure 2) is a hand-held device that is typically used to measure voltage, current and test for connectivity between two points in a circuit. The oscilloscope is used to display and analyse time-varying signals e.g. sine-wave signals. Because of their cost, weight and size, these instruments are not suited for home environments.

The developed solution, the Home Electronics Laboratory Platform (HELP) is illustrated in Figure 3. HELP consists of a hand-held 3-in-1 device that combines the functionality of a traditional oscilloscope, waveform generator and multimeter[2]. This can be interfaced with a standard PC via a USB interface. At MTU we designed, tested and produced a custom breadboard which had an integrated power supply. We also sourced a protective carrying case for the MTU breadboard to enable both it, and any electronic circuits assembled on it, to be transported safely.

2.4. Implement Solution

As Ireland entered its second lock-down (October 2020), at MTU we chose to replace many in-person laboratories with take-home laboratories. The HELP platform along with the necessary components (resistors, capacitors, operational amplifiers, etc.) were posted to registered students. This enabled first and second year laboratories in the core areas of analog and digital electronics to be realized. In third year, digital electronics focuses on the design and implementation of digital circuits using specialised devices called Field-Programmable Gate Arrays (FPGA) and Basys 3 Artix-7 FPGA Trainer Boards were posted to support this learning. The Electronic Engineering programme at MTU emphasises embedded system design and students learn about and use single-board computers from the Raspberry Pi Foundation along with microcontrollers from Arduino (Arduino Uno) and Microchip Technology (PIC24F Development Board). These devices were also posted to students to support introductory and advanced modules in this area. Telecommunications is another core area of Electronic Engineering. The ADALM Pluto Software-Defined-Radio (SDR) is a USB-powered physical module that enables students to explore the fundamentals of software-defined radio (SDR), radio frequency (RF) and wireless communications concepts and applications. Finally, USB data acquisition kits are modules that enable devices to be connected to a standard PC/Laptop and for data to be read from those devices and/or sent to those devices. Table 1 then summarises the range and quantities of key devices that were posted. Smaller items e.g. resistors, capacitors, operational amplifiers, sensors etc. that would also have been sent to student's homes are not recorded in this table.

Equipment	No of Units Sent
HELP kits	120
Raspberry Pi	25
Arduino UNO development kits	60
PIC24F Curiosity Development Board	35
ADALM Pluto SDR	25
Basys 3 Artix-7 FPGA Trainer Board	35
USB data acquisition kits	40

Table 1: Range and volume of core take-home equipment sent to students

2.5. Evaluate

Student and staff feedback were used to evaluate the impact of the HELP kits. Student feedback was gathered via a questionnaire from students who had experienced in-person laboratories, simulation-based laboratories, and the HELP kits. The findings from this research is reported in Hill et al. (2021). This article focuses on staff feedback which was gathered via focus groups. Within MTU, 13 staff members teach on the Electronic Engineering programme. Ten staff members had used take-home laboratories during the period January to June 2021.

[2] The 3-in-1 multi-function device used in the HELP kits is produced by Qingdao Hantek Electronic Co., Ltd and the specific device used was the Hantek 2D42 model.

All ten were invited to participate and eight agreed. Six of these participants would be regarded as experienced lecturers with more than five years of teaching experience. The focus groups were approximately one hour in duration and were conducted on-line during the months of September and October 2021. The focus groups explored participants opinions related to the technical strengths and limitations of the HELP platform, how take-home laboratories supported students to learn, the challenges faced by students, how take-home laboratories impacted the teaching and assessment of the practical component and the planned use of the HELP kits post COVID-19.

The first author facilitated the focus group sessions. Stewart and Shamdasani (2014) note that during focus group sessions it is reasonable to record "observational data" which can then be used to support the data analysis process. A collaborative digital whiteboard was used for this purpose with a frame or whiteboard for each of the main questions explored. During focus groups, both the first and second authors independently recorded summary notes in this collaborative space. The link to this space was shared with all participants at the start of the session so that they could view the notes that were being recorded, confirm that those notes were a reasonable (if incomplete) summary of what was being said, edit and add notes as appropriate. The focus group sessions were also recorded and then transcribed using an automatic transcription service.

The transcripts were then analysed using content analysis (Krippendorff 2004; Erlingsson and Brysiewicz 2017). Erlingsson & Brysiewicz (2017) recommend that content analysis begin by identifying meaning units i.e. short sections of the text that focus on a particular aspect. These can then be condensed and codes attached to those condensed meaning units. Codes are then examined to identify relationships and codes that are related form categories. Key themes are derived through a process of reflecting on these categories and the relationships between categories. To counteract researcher bias, the first three authors participated in the content analysis process. When we started with the first focus group transcript, it became apparent that the notes created on the collaborative white board corresponded with the condensed meaning units we were generating and were consequently adopted as condensed meaning units. For completeness, the first and third author independently reviewed each of the transcripts and the recordings to ensure that the condensed meaning units accurately reflected the focus groups sessions and augmented these where necessary. The third author then integrated the condensed meaning units from each of the three focus groups to create an initial overview. The first author coded the data, created categories and initial themes. These were shared and discussed to arrive at the final themes. The first author then returned to each of the transcripts and focus group recordings in light of the overall findings to ensure that the findings accurately reflected the focus group sessions. Stewart and Shamdasani (2014) note that it is acceptable to make minor edits to the transcripts by for example, removing redundant half-finished sentences, odd phrases, repeated phrases, etc. We adopted this practice in section 3 to enhance the readability of the quoted material.

3. Findings

The data analysis revealed that staff were extremely positive regarding the take-home laboratories because "I think it just helped them to become real engineers, not just follow the labs notes quickly in two hours" (Participant No 8).

3.1. Perceived Student Learning

A key finding was that staff felt that the take-home laboratories encouraged and enabled students to work in a different way that developed independent learning skills. Participants noted that "Practical laboratory-based independent learning can now be done using that kit" (Participant No 4). "I just find that labs sometimes are a bit rushed. They're just trying to tick the boxes. Whereas when they're at home I think they have to be a bit more self-directed really, or at least they get to explore a bit more I think, and think about it at their own pace" (Participant No 5). Participant No 8 explained how "there is a really great community of Arduino development out there and I strongly encouraged them all the time to find a solution themselves, on the Internet and to simply work independently. … Certainly, that wouldn't happen at all if we were all together in the classroom. This, remoteness, I think it has actually had a good impact on them, they were becoming more independent thinkers and developers – it was very good" (Participant No 8).

In the absence of a supportive on-line community, participants felt that the take-home kits helped "to get them [students] focused and work with each other. It enabled the students to actually talk to each other on WhatsApp when they were having issues that they could tell each other practical stuff and I think it really helped" (Participant No 2). "I mean they were obviously sharing and talking on the web, using Discord or whatever communication links they were using" (Participant No 5).

A common observation was that the take-home laboratory provided more time as "they can take the equipment home if they didn't get the lab finished, or they didn't feel that they quite understood it. They're not asked to leave the lab because there is another class coming in" (Participant No 1). This opportunity to spend more time with the physical equipment enhanced learning. "I did this twice, this module. The year before it was in the lab and last semester, it was at home. And I see certainly the improvement … the students asked kind-of more clever questions. I received more deep questions like, why this? Because they simply … it was obvious, they simply spent more time thinking and playing with it, so they discovered more questions for me" (Participant 8). More time was also created because with traditional in-person labs "every time they come in, the first thing they had to do was wire the boards. … So, you're right they might actually lose maybe 10 minutes, 15 minutes and, at the end they have to dismantle it" (Participant No 7) whereas with their own equipment at home it was ready to go from the previous week.

The focus groups revealed trouble-shooting to be a double-edged sword. On the one hand the "one good thing that I noticed is that when you are in class if something doesn't work they call you. So, you come and you look at the code, or you look at the wiring and then you explain to them what's wrong. When they are at home they do much more troubleshooting themselves because they know they have to send you an email, they have to wait for you to reply and sometimes they didn't have the patience, so they look at it and they find the answer and funny enough, they'll tell you. They'll say, I had a problem, but I found a fault, you know they are kind of happy with themselves" (Participant No 7).

3.2. Achieving Practical Learning

Over 50% of the contact time in the BEng. in Electronic Engineering at MTU is dedicated to experiential, laboratory-based learning. There were concerns that COVID-19 would undermine this philosophy. A second broad finding was that participants found that the take-home laboratories "just enabled the program to continue, as we didn't have to change any module descriptors" (Participant No 1) and "the kit supported everything that was required for the module. It supported it 100%" (Participant No 2). Participant 4 noted that "it allows them [students] to replicate what we would normally do in the laboratory" while Participant No 7 commented "I didn't have to change anything at all". Some of this positivity can be attributed to COVID-19 and the recognition that "like the alternative was that they did everything in Proteus [a simulation package] … we'd be left with second years, who had never built a circuit in their lives which would have been a huge deficit for them" (Participant No 1). Participants recognized that the take-home equipment "might be more essential for some modules, less for others. Like the one I had, certainly it wouldn't be possible without the home kit to practically deliver on this model at all" (Participant No 8).

3.3. Technical Functionality

The third broad aspect that contributed to the positive rating of take-home laboratories was the technical functionality of the equipment, especially the HELP kit. Four of the eight participants used the HELP kits extensively and found it "brilliant…it's absolutely brilliant … the concept is fantastic" (Participant No 2). They identified the "ease of use was the first strength as far as I'm concerned… It did everything that I needed to do… it was very straightforward and the students were able to do exactly the same thing as I was doing. Relatively easier than using a physical oscilloscope." (Participant No 2). Participant No 7 observed that "it was perfect and now this semester I'm doing the labs in class but I'm using the equipment that we designed during the pandemic, because it's actually better equipment than what we had before". While participants acknowledged that the low-cost nature of the equipment meant that it was technically limited compared with traditional laboratory equipment, at times this was also an advantage as you "could show them aliasing and things like that very easily" (Participant No 5). It also integrated well with other hardware "we gave them out the LabVIEW modules, as well as the Hantek[3] and they could actually get that talking to the Hantek, generate waveforms with the LabVIEW gear, look at it on the Hantek, stuff like that, so that actually tied together really nicely" (Participant No 5).

3.4. Troubleshooting Challenges

The dominant challenge identified by participants was associated with troubleshooting circuits. If students encountered a problem "they weren't prepared to show me an image of the work that they've done so, I could see Oh that's miss-connected here or that's not connected here. I couldn't get the feedback that you'd get in the lab by standing over them and saying that wire is loose or that's in the wrong place … Less of an issue with second year and third years.. they know what they're doing but first years that would have been an issue." (Participant No. 2). "Yeah I'd agree. The ability to troubleshoot when, say, the wire is in the wrong place, it was almost impossible - especially with first years. If they were unable to describe what the issue is to you, maybe over an email, it was very difficult to troubleshoot." In addition, many students were using low cost, web cameras with limited resolution and "it is a bit difficult for me to help them because it's very small detail" (Participant No 6). In some cases, this challenge was compounded by the fact that students "can't share the Hantek screen … you don't know what buttons are being pushed" (Participant No 4) on the physical Hantek device.

3.5. Other Challenges

Participants also noted that there was a "large learning curve with the Hantek if you haven't used an oscilloscope before" (Participant No 4) and that "giving them the required skill sets is hard to do remotely when you can't see what's going on" (Participant No 4). Staff acknowledged that the HELP platform is not equivalent to industry standard equipment and

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[3] When participants mention "Hantek" they are referring to the 3-in-1 multi-function device that formed part of the HELP kits (see figure 3). This is produced by Qingdao Hantek Electronic Co., Ltd and the actual device used was the Hantek 2D42 model.

expressed concerns that we would be doing students “a disservice if we didn't have an opportunity for students to sit down with a real piece of test equipment” (Participant No 3) before going into industry. Other staff found that some students “would be a bit worried to damage the equipment. So, it was good for them to know what actually if they were careful, and if they were following the manual then there was no danger at all” (Participant No 7). A challenge for academic staff was that it was more time consuming for them “there's more value for the students, but it is more work because you have to set it up, you have to try quite a lot before to make sure it works, so you have to try with the camera see what the students will see because you can't really do it when the students are actually online. So, it takes more time” (Participant No 7). Staff also acknowledged that take-home laboratories necessitated a significant logistical workload associated with preparing equipment and then getting equipment and components to and from students. Finally, Participant No 8 also suggested that remoteness might impact on feelings of satisfaction when things worked because “you don't have an opportunity to demonstrate to others what you achieved…. they don't have really a way of sharing their excitement”.

3.6. Technical Limitations

The original HELP kit was limited to a single +5V supply and this was identified as the most significant limitation. Many operational amplifiers require larger bipolar supplies and “the biggest limitation was that it didn't have the plus and minus 15 volts on it”. The single +5V supply also meant that some established laboratory experiments either had to be modified to accommodate this limitation, alternative components sourced or the bulky breadboards sent to students. Participants also noted that the clock on the Hantek 2D42 was insufficient to drive some of the traditional TTL-based components used in digital circuits so those components needed to be replaced with equivalents. More significantly, Participant No 2 identified that “some of the labs that would have been done in [module name] we wouldn't have been able to do them as well as we would have been able to do them in the lab. We'd normally have two power supplies… say we'd be doing Kirchoffs law, stuff like that … which is the experiment that has the most meat on it, that really gets the students thinking. We want two power supplies that would be in reverse so they can do circuit analysis.” Hence in a small number of cases, the technical limitations had an impact on the learning that what was possible.

4. Discussion

As outlined in Section 1, take-home laboratories have not featured significantly in the engineering education literature. The literature that does exist, mostly derives from enthusiastic individuals that are describing the take-home laboratories that they themselves developed (Stark et al. 2013; Reck, Sreenivas, and Loui 2019; Schajer 2022) or from on-line universities (Long, Florance, and Joordens 2004; Monzo et al. 2020). In both cases the evaluative focus tends to be on student feedback or/and student performance. The perspectives of academic staff that are not necessarily champions of take-home laboratories is largely non-existent. The contribution of this article is then to document the experiences of these academic staff with take-home laboratories, who prior to this experience would have exclusively been supporting traditional in-person laboratories. Given that these staff characterize the majority of engineering faculty, their perspectives are critical in order to arrive at a balanced understanding of the merits, limitations, and possibilities of take-home laboratories.

Our findings suggest that take-home laboratories can be likened to a double-edged sword. Based on their experience, the majority of participants were convinced that take-home laboratories enabled students to become more self-directed and independent engineers. This was enabled, in part, because learners had more time to engage with the physical equipment and, in part, it was driven by necessity. In comparison, in-person laboratories do not afford the same time opportunities and staff provide more help for students. In our view, enabling the development of independent learning is a really significant advantage associated with take-home laboratories. On the other edge of that sword, when students genuinely experienced problems with take-home laboratories, staff found it challenging to provide quality feedback that would help students to solve those problems. The nature of the subject (constructing circuits with small detail), technology (low resolution cameras) and student inexperience with describing/documenting problems all contributed to this challenge.

We arrive at a really interesting question. Is the challenge that is likely to result from take-home laboratories worth the dividend of becoming a more independent learner/engineer? Research has shown that students *report* learning less in environments that feel messy, less organized and more challenging, yet performance tests reveal that students actually learn more in these environments (Deslauriers et al. 2019). This perhaps cuts to the nature of learning. As engineers many of us appreciate that learning is difficult, frustrating, messy and takes a lot of time and effort, yet as instructors we strive to remove some of that difficulty, frustration, time and effort for our students. In doing this, are we really helping students to understand what real learning looks like and are we preparing them for learning outside of the university.

Related research reported by Hill et al. (2021) and Bishop et al. (2021) compared take-home laboratories with simulated and/or in-person laboratories but from the student perspective. Their findings largely support the findings reported here, which helps to add trustworthiness to our findings. For example, in the study by Hill et al. (2021) over 90% of the student respondents agreed that take-home laboratories provided more time to complete experiments relative to in-person laboratories. Likewise, over 65% of those student respondents acknowledged the support that they received from their peers within the class. Students also identified the challenge associated with supporting practical learning in a take-home environment, that solving problems was a real issue and resulted in a lot of frustration for them (Hill et al. 2021). This aligns well with the findings presented in Section 3.4. Bishop et al. (2021, p. 622) conclude that students were really satisfied with the take-home experience with "over 80% of the students preferring to complete these activities at home in the future, rather than attending in-lab sessions". In common with our findings and those of Hill et al. (2021), the majority of the students agreed that the take-home laboratory provided them with more time relative to in-person laboratories and that the take-home laboratory allowed students to better manage their own time. Similarly, troubleshooting circuits was also identified as a key challenge for students, especially first year students.

This research was conducted in September and October of 2021 when (in Ireland) students were permitted back on campus for laboratories. Perhaps the real testament to the potential of the take-home laboratory was that many of these participants were committed to their continued use "so I would continue on using it, I guess this year again, this semester. I mean we'll be issuing the Raspberry Pis which we did last semester as well" (Participant No 5) and "I would like to keep this opportunity and give it to students to explore beyond the lab" (Participant No 8). At this time, staff were contemplating how the take-home kits might complement the traditional in-person laboratory "in the first year you'd imagine that the main hardware that they'll be using will be the Hantek, the HELP kit. So, they're bringing that in with them, they'll be setting it up in the lab, there'll be doing their experiments and testing them, but with the opportunity to take it home as you said and complete it, and then they'd be bringing in again next week". Others were considering how the take-home kits might extend the in-person laboratory "Rather than stepping through a set of labs … lab one, lab two, lab three, we could have more open type stuff available to the students" (Participant No 4). Aligned with the work reported by Onet et al. (2022), the take-home laboratory offers the potential to transform the laboratory programme and create opportunities for more project-based learning activities. This could take the form of an individual or team-based project that extends for the duration of the semester or a blended approach where earlier weeks of the laboratory practice consist of more directed, independent work and later weeks a more open-ended team-based project. Creating the need to do some practical work outside of the laboratory will help foster independent learning skills while the in-person contact will enable academic staff to provide effective feedback, support and troubleshoot guidance.

The authors are collaborating on an EU Erasmus+ project, HELP, the aim of which is to both develop the technical functionality of the HELP kit and also explore how the HELP platform can be used to support learning. Following on from these focus group sessions, technical revision V1.1 added a bipolar +/-12V supply and also addressed the other technical issues outlined in Section 3.6. These improvements are detailed in Onet et al. (2022). Presently the price of the HELP kit is largely dictated by the multi-function Hantek 2D42 device. The project team is currently working on revision V2.0 which will add an on-board function generator to the MTU protoboard and explore alternatives to the Hantek 2D42 device. HELP V2.0 will also incorporate an on-board Arduino Nano microcontroller that will enable HELP V2.0 to support introductory Embedded Systems Development, in addition to Analog and Digital Electronics.

5. Conclusion

The contribution of this article is to explore and document the experiences of engineering staff with a range of take-home laboratories within the discipline of Electronic Engineering. The objective was to identify the advantages, limitations, and possibilities of take-home laboratories. Participants generally agreed that take-home laboratories supported the development of self-directed/independent learning competencies and troubleshooting skills to a greater extent than in-person laboratories do. There was strong agreement that take-home laboratories provided more time which then enabled that independent learning and deeper learning. Finally, participants identified that the take-home laboratories that were implemented were a good replica of the in-person laboratory. This was especially true for the HELP platform that was developed to support analog and digital electronics in the early years of the programme. The key challenge that was identified was supporting students, especially first year students, to troubleshoot their practical work when the experiment did not work as anticipated. This challenge resulted in frustration for students, but as noted earlier, useful learning. This is an ongoing Erasmus+ research project and all of the technical limitations that were identified with the HELP platform have been addressed.

These findings have very obvious implications for on-line and distance learning programmes associated with the discipline of electronic engineering. Providing feedback and troubleshooting in these environments is a real challenge, and future research should try to address this issue. We also believe that this research has implications for traditional in-person electronic engineering programmes. Our findings suggest that we could be asking how and when take-home and in-person laboratories could be blended to enhance existing practices. Our current focus is to explore further the opportunities created by take-home laboratories, to redesign laboratory practices and to evaluate the impact of these changes on student learning.

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