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A Blended On-Campus and At-Home Approach to Laboratories on Electronic Circuits

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Abstract. This paper presents a blended approach to organizing laboratories for undergraduate Bachelor-level courses on electronics circuits and systems. The main idea is to combine on-campus laboratory sessions with at-home experiments performed individually by each student as homework. This way, students can enjoy the advantages of both on-campus and at-home experimental work while avoiding most of their limitations. An essential prerequisite is to provide each student with a portable laboratory kit. Such a kit was developed by the authors with the Erasmus+ project *Home Electronics Laboratory Platform* (HELP). The HELP laboratory kit comprises of a portable signal generator & measurement instrument and an electronic board developed specifically for this purpose, which includes several functional blocks alongside the usual breadboard for assembling circuits with discrete components. The paper describes the HELP kit in some detail, then the results of an experiment designed to assess the impact of using it. An administrative unit of 18 third-year students was split randomly in two equal-size groups, one that had only traditional on-campus lab classes while the other nine students were given HELP kits and followed the proposed blended on-campus and at-home approach for their lab classes. All students received end-of-semester marks for both laboratory activity (as an average of four tests and homework completion) and a written exam (solving four problems on circuit analysis). The group that used HELP kits performed substantially better than their counterparts, both in respect to laboratory – average lab mark almost two points (out of ten) higher – and written exam – average exam mark over one point higher. These results indicate that the blended on-campus and at-home approach to laboratory classes helped improve the overall learning experience for students, with positive impact not only on their lab performance but on their understanding of electronic circuits, as well.

Key-words: Assessment of laboratory work; electrical engineering education; home electronics laboratory; online learning; portable electronic laboratory kits.

1. Introduction

Practical experiments are crucial for science and engineering subjects because they allow students to acquire essential skills such as setting up and conducting an experiment, effectively using specialized equipment, testing and debugging. Fundamental undergraduate courses in electronics require practical experiments usually performed with standard laboratory equipment.

Due to the Covid-19 pandemic lockdowns, universities were forced to shift to online learning. While lectures were easier to adapt to distance learning, the delivery of application classes with practical experiments, such as laboratories, have been severely constrained [1, 2]. In many cases students have undertaken their laboratory activities at home through SPICE simulations, remote laboratories [3–6] or using virtual instruments [7, 8], that do not provide the experience of authentic experiments with real laboratory equipment.

To overcome these drawbacks, take-home laboratories, already-used by online-universities [9], were introduced by several traditional universities as emergency response to Covid-induced lockdowns [10, 11]. In general, students reacted very well to this approach, that allowed them not only to perform real-life experiments during the pandemic but also to better manage their learning process, as the laboratory activity was no longer time limited and under peer pressure. However, limitations of this approach – such as, lack of experience with standard equipment laboratory students were likely to work with post-graduating – were also recognized by students and teachers. The experience gained with take-home laboratories led to the development of a blended approach suited to post-pandemic classes, which is described in this work.

The rest of the paper is organized as follows: Section 2 starts with a review of the traditional, on campus laboratories and their computer-based virtual counterparts, focused on factors that limit their effectiveness in developing skills necessary to students in Electronics. Next, the main conclusions drawn from using the take-home laboratories during the Covid lockdowns are discussed. This helps introduce the blended approach to laboratory activities presented here; it combines on-campus lab sessions with at-home individual experiments performed as homework. The latter are enabled by a *Home Electronic Laboratory Platform* (HELP) developed by the authors, that is described in Section 3. Section 4 presents a case-study: a group of 18 third-year students was split randomly in two equal-size groups, one that had only traditional on-campus lab classes while the other nine students followed the proposed blended on-campus and at-home approach. The main conclusions of this work are discussed in Section 5.

2. Review of Several Approaches to Laboratory Classes on Electronic Circuits

The traditional, on-campus, laboratory is a key element of conventional teaching & learning engineering subjects. A large amount of student time is allocated to application classes (lab/project) and individual study. For electronics, it involves weekly applications classes with activities focused on circuit analysis and characterization through simulation using SPICE-based programs and by performing experiments on relatively simple test setups assembled by students during the lab class.

Typically, practical experiments require a set of standard laboratory equipment (power source, signal generator, oscilloscope, multimeter), a breadboard and a set of electronic components, wires and connectors. Often, it is not possible/practical to provide a complete setup for each student, so students have to work in pairs.

Usually, students are required to complete an experiment that involves sizing or at least analysing mathematically the circuit, then assembling it on the breadboard, checking that it operates correctly and/or debugging it, then performing measurements, collecting and processing data – within a two-hours session. Therefore, it is necessary to curtail the complexity of circuits students can perform in laboratory experiments. Moreover, circuit assembly and debugging can take a large portion of the allowed time, reducing the time students can spend on understanding the circuit functionality and experimenting on it. Furthermore, there is no week-to-week continuity: the assembled circuits will be removed from the boards because the next group of students will attend the same lab.

Hands-on lab activities have been severely constrained during the Covid-19 lockdowns. In many cases, students have performed their laboratory activities at home through SPICE simulations, remote laboratories [3–5] or using virtual instruments [7, 8]. However, these PC-based activities do not provide the experience of authentic experiments with real laboratory equipment.

To overcome these drawbacks, take-home laboratories, already-used by online-universities [9], were introduced by several traditional universities as emergency response to Covid lockdowns [10, 11]. For example, in the summer of 2020 the Dept. of Electrical & Electronic Eng. at the *Munster Technological University* (MTU) developed a portable laboratory kit and distributed them to 120 students at the beginning of the 2020-2021 academic year [10].That kit provided equipment similar – if simpler - to the one available for on-campus lab classes, such as oscilloscope, multimeter, signal generator, power supply, breadboard. The aim was to enable students to perform laboratory experiments during the lockdowns, essentially on their own but with support provided remotely by teachers.

In general, the take-home laboratories were very well received by students. Besides the possibility to conduct experiments while in lockdown, students appreciated the advantages this approach brought in, such as the fact that the laboratory activity was no longer time limited and that mistakes could be identified and fixed without undue pressure from peers and teachers. Also, by working individually – even if making use of the remote support available – they gained confidence in their ability to prototype electronic circuits [10, 11]. However, the students also indicated their preference to using standard lab equipment in the future, as well as returning to in-person interaction with their colleagues and teachers [10, 11].

We used this experience to develop a blended approach to laboratory activities suited to the post-pandemic educational environment. The main idea is to combine on-campus laboratory sessions with at-home experiments performed individually by each student as homework [12]. A portable laboratory kit was provided to each student, allowing them to perform some hands-on circuit experiments at home; on-line support was also provided, in conjunction with in-person tutoring and assessment during on-campus lab classes. The laboratory work is organized in three steps, somewhat similar to the typical development stages of a real-life project for prototyping electronic circuits:

1) on-campus: the teacher and students review briefly the theoretical background, then the teacher helps students perform experiments on basic circuit examples; next, the teacher

sets requirements for homework and provides guidelines;

2) at home: students complete their homework individually, but with free access to remote support provided by an Online community. The homework usually involves the implementation of electronic circuits with discrete components assembled on a breadboard, as well as their debugging and characterization by using the portable laboratory kit;

3) on-campus: students present their homework; the teacher assesses their work and help them debug their circuit(s), if necessary. Next, students are required to adjust/enlarge their circuits in order to meet new requirements. At this stage they use standard laboratory equipment and may work in pairs.

Thus, on-campus classes help students develop competences in analyzing and characterizing electronic circuits by using standard lab equipment, as well as enhancing their team-work abilities. The at-home individual work helps them develop competences in prototyping electronic circuits and abilities for circuit debugging and learning from mistakes. Also, students get used to planning and managing their work, and to documenting and presenting experimental results.

3. *The Home Electronic Laboratory Platform* (HELP) Kit – A Technical Overview

3.1. General description

The Home Electronic Laboratory Platform (HELP) was developed within an EU-funded Erasmus+ project [13]. It comprises three elements [12], as shown in Fig. 1:

- the HELP kit – effectively a portable laboratory that allows students to perform at- home experiments on electronic circuits, then present them at on-campus lab classes;

- the HELP OnLine platform – a virtual community of practice that allows students and teachers to share experiences, post and access materials, etc;

- the Help Courses – a library of teaching materials that provide support for completion of homework. They include basic theoretical background, as well as specific guidelines.

This paper focuses on the HELP kit presented in Fig. 2. It consists of a compact, standalone 3-in-1 handheld instrument - the Hantek 2D72 portable scope [14] - and a USB-powered electronic board, designed specifically for this purpose.

The Hantek 2D72 instrument provides an Oscilloscope able to monitor two channels for frequencies up to 70MHz, an *Arbitrary Waveform Generator* (AWG) able to provide sine- and square-waves with programmable frequency (up to 1MHz) and amplitude (up to 2.5Vpk), as well as a Digital Multimeter [14].

The electronic board described here was designed by the Technical University of Cluj-Napoca (TUCN) team as an upgraded version of the kit developed by MTU in 2020.

Fig. 1. HELP environment core elements.

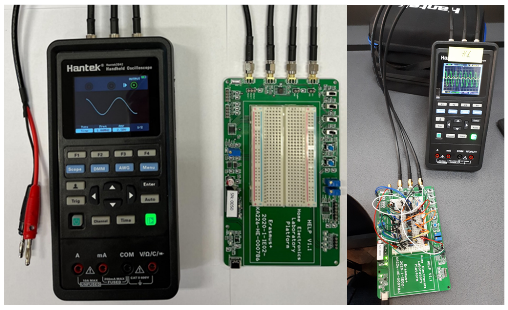

Fig. 2. The HELP kit consists of a 3-in-1 handheld instrument and an electronic board.

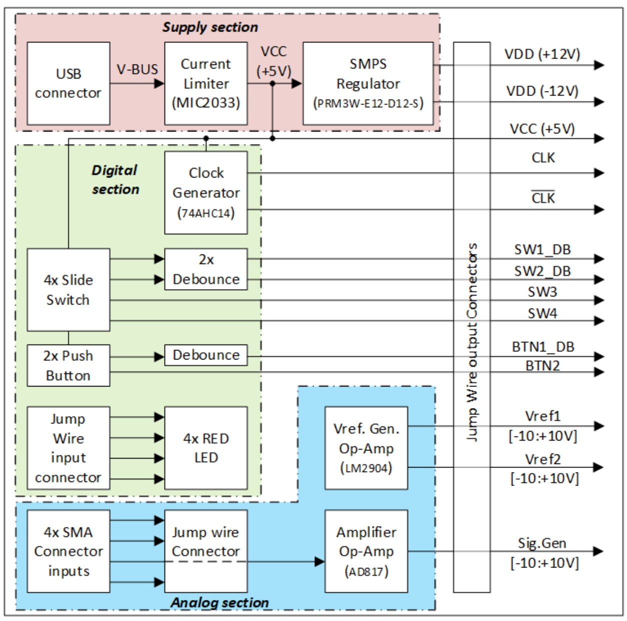

Fig. 3. Block diagram of the HELP kit electronic board. Its three main sections are highlighted by different background colours: Power Supply (pink), Analog (blue) and Digital (green).

It comprises not only the usual breadboard and the required wires and cables, but also several functional blocks implemented on-board that expand the range of experiments students can perform. The main additional features are:

symmetrical supply lines, $\pm$12V

power amplifier able to scale up the signal provided by the Hantek instrument, to an amplitude of maximum 10Vpk for the sinewave.

DC voltage sources with values adjustable manually between $\pm$10V

digital clock generator, with frequency adjustable from 0.3Hz to 210Hz

several switches and push buttons (both straight and debounced) to generate logic inputs and LEDs to monitor logic states.

Fig. 3 presents the block diagram of the HELP board. The functional blocks are grouped in three sections: the power supply section, the analog section and the digital section. Their simplified schematics are presented in Fig. 4. These sections are detailed in the followings.

3.2. The Power supply section

The HELP board Power Supply is marked in Figures 3 and 4 by pink background. It takes in a 5V voltage supply from the USB connector and provides $\pm$12V symmetrical supply lines with 125mA current capability. They were implemented by using the PRM1W-E12-D12-S from CUI Inc [15] and appropriate filtering. Green LEDs indicate normal operation of the supply lines. The section includes overcurrent protection for the USB port that supplies the board. The 500mA current limitation is implemented by the MIC2033 integrated circuit from Microchip Technology Inc. [16]. It has an inrush current control for power up, and a FAULT output that indicates the OCP event. The latter is used to turn on a red LED, thus signaling the user when the overcurrent protection is activated.

3.3. The Analog section

The analog section is marked in Figures 3 and 4 by blue background. It comprises a power amplifier with a voltage gain of four and two DC voltage sources with values adjustable manually. The power amplifier gains up the signal generated by the Hantek's AWG – which has a maximum amplitude of 2.5V – to an amplitude of maximum 10V, and has an output current capability of 90mA. Two DC reference voltage generators provide trimmable voltages in a range of $\pm$10V; with a current capability of 30mA. Furthermore, they can drive large capacitive loads, up to tens of uF.

3.4. The Digital section

The digital section of the HELP board is marked in Figures 3 and 4 in green background. It comprises a clock generator, four slide switches and two push buttons to generate digital inputs and four LEDs to monitor logic states. The clock generator provides a 5V clock & inverted clock signals with frequency adjustable through a trimpot resistor, from 0.3Hz to 210Hz. The signals coming out of two slide switches and one push button are debounced.

Fig. 5.a) presents a photograph of the electronic board designed, implemented and tested by the TUCN team. The connectors placed on the left-hand side of the board provide a robust interface with the Hantek instrument or with standard laboratory equipment. The free space

on the right hand-side of the breadboard allows for an additional breadboard to be connected, doubling the space available for circuit assembly.

Fig. 5. b), presents the protective case with custom foam that fits the electronic board. This helps ensure that the board can be transported without jeopardizing the electronic circuits assembled on it. The case also hosts several accessories essential for the ease-of-use of the HELP laboratory kit: one USB-A to USB-C cable for supply, three SMA-BNC cables that interface the Hantek 2D72 Signal Generator and Scope channels connections with the electronic board, one SMA to banana cable for the digital multimeter connection, one trim screwdriver for adjusting the trimpots, jump wires for assembling circuits on the breadboard and a set of electronic components.

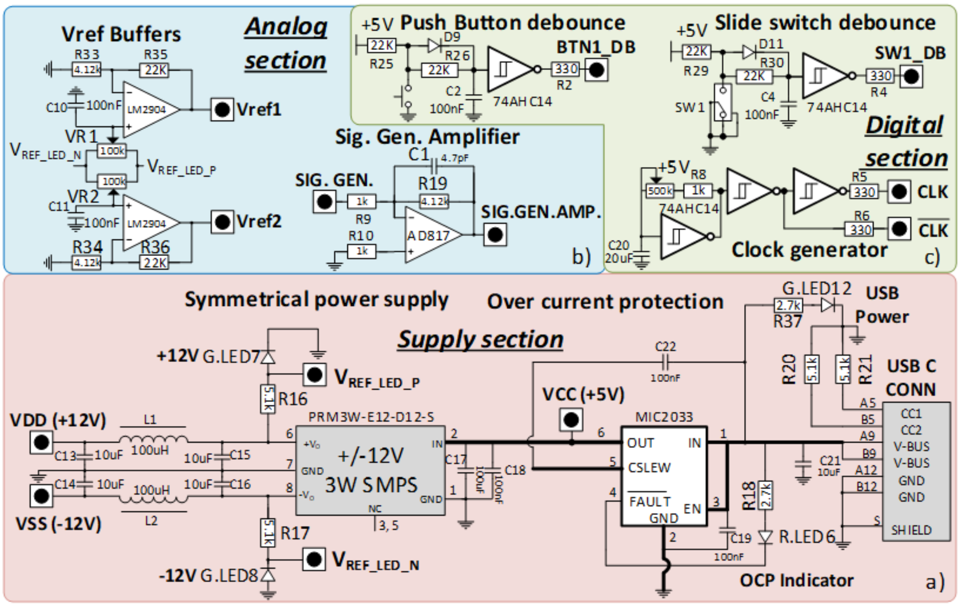

Fig. 4. Simplified schematics of the three sections within the HELP kit electronic board.

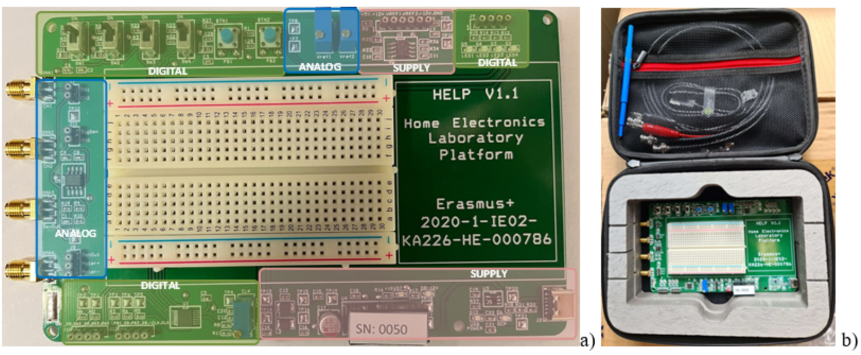

Fig. 5. a) Photograph of the HELP kit electronic board; b) HELP kit electronic board in a protective case.

Table 1. HELP kit compared against similar, commercially-available, kits for circuit experiments

Ref.	Power supply	Signal Generator	Measurement	Support Required	Cost
[10]	5V fixed power supply	2.5Vpk, 1MHz	40MHz, 2-channel scope, DMM	Self-sufficient	\$150[a]
[9]	±5V,12V, ±15V fixed power supplies, 100mA current capability	15Vpk; 351kHz	2-channel scope	1PC	\$65
[17]	15V programmable power supply, 50mA current capability	5Vpk, 170Msps	2-channel scope, DMM, network/spectrum/ digital analyzer	PC	\$236[b]
This work; HELP kit	±12V programmable power supply, 125mA current capability 5V fixed power supply, 380mA current capability ±10V programmable power supply 30mA current capability	10V, 1MHz	2 channel 70MHz Scope, DMM	Self -sufficient	\$200

3.5. Comparing the HELP kit against similar experimental kits for electronics

Table 1 lists the main features of the HELP kit alongside three similar portable kits for electronic experiments. The HELP kit is 30% more expensive than the first laboratory kit, develop in 2020 [10], but overcomes the main limitations of that version: (i) only 5V unipolar voltage supply available (which caused confusion to students used with OpAmp-based circuits with symmetrical supply lines), (ii) amplitude of analog inputs limited to a maximum value of 2.5V, as provided by the Hantek 2D42 instrument [14] and iii). limited options for generating static analog and digital stimuli.

The kit presented in this work provides more functionality than its counterparts listed in Table 1, except for the commercially-available kit described in [17], the only one to provide the network spectrum analyzer. However, the kit is more expensive than ours and works only in conjunction with a PC/laptop, similar to the kit in [9].

4. Blended laboratories on "Systems with Analog Integrated Circuits" - A Case study

During the 2021-2022 and 2022-2023 academic years the HELP kit described in Section 3 was used for two courses within the Applied Electronics BSc. program of study at the Faculty of *Electronics, Telecommunications and Information Technology* (ETTI) of the TUCN. First, the Help kit was deployed to students who volunteered to use it for an individual project involving the design and implementation of an Analog Front-End. The results are presented in [12].

The case-study presented here involved the blended on-campus and at-home laboratory sessions described in Section 2. The participants were third-year BSc. students attending the *Systems with Analog Integrated Circuits* (SAIC) course. The general objective of the SAIC course was to develop students' competencies regarding the analysis, design, verification and characterization of a wide range of analog systems implemented with Operational Amplifiers (OpAmps) and linear transconductors (Gm-cells). Students attended weekly two-hours laboratory sessions over a 14-weeks long (standard Romanian) academic semester. In general, two lab sessions were allocated to each of the following classes of linear or non-linear circuits implemented with OpAmps and Gm-cells: Amplifiers (controlled-gain and instrumentation), Precision rectifiers and peak detectors, Continuous-time filters, Harmonic oscillators, Comparators (Signal generators, Analog multipliers. Within a pair of lab session, students were required to analyse and characterize several circuit implementations through both SPICE-based simulations and physical measurements.

An administrative unit of 18 students was split randomly in two equal-size group: one that had only conventional on-campus lab classes while the other nine students were given HELP kits and followed the blended on-campus and at-home approach.

Students within the "reference" group had exclusively on-campus lab classes, worked in pairs and using standard laboratory equipment. During each lab session they were asked to assemble several circuits on a breadboard, assess their operation, perform measurements and process data in order to derive the main circuit parameters. Typically, three to four representative implementations were studied for each class of circuits. Note that students in this group were also required to complete preparatory homework, which involved analysing circuits mathematically and through simulations. For example, the session on Amplifiers covered two implementations of controlled-gain amplifiers and the standard 2-OpAmp and 3-OpAmp topologies for implementing Instrument Amplifiers [18]. First, students analysed these circuits as part of their homework; once in the laboratory, they started by assembling one of the simplest of these circuits on the breadboard (*e.g.* the IA implemented with two OpAmps in the inverting configuration). Next, they checked its functionality – including possibilities to change the gain and the DC level of the output voltage, then focused on deriving (through measurements) the voltage transfer function and assessed its accuracy with respect to the reference set by theoretical analysis. Also, they measured the CMRR and the bandwidth. As homework, students were required to analyse through simulations other types of IAs. During the second lab session on this subject, they repeated the experiments on the IA implemented with two OpAmps in the noninverting configuration, then on the 3-OpAmp topology.

During the first lab class on Amplifiers students within the HELP group performed similar experiments as the "reference" group, but part of the time was allocated to defining and discussing their homework. They were required to implement and study at home the 2- and 3-OpAmp IA circuit topologies. Students were given guidelines and could use the Help Online platform for further support. At the start of the second lab session on Amplifiers, students presented their homework; this included the actual demonstration of their circuits, with measurements performed by using standard lab equipment, and comparing the results obtained in the lab with those obtained at home, as recorded in their reports. Next, students were required to turn their 3-OpAmp voltage-voltage IA into a 4-OpAmp voltage-current IA and characterize it.

Students received end-of-semester marks for both laboratory activity (as an average of four written tests and assessment of their homework) and a written exam (solving four problems on circuit analysis). Evaluation was done under exactly the same conditions for all students, with no differences between the two groups.

5. Assessment of the Educational Impact of Using the Blended Laboratories Based on the HELP Kit

5.1. Students feedback

At the end of the semester, the students within the HELP group were asked to evaluate their blended-laboratory experience through a questionnaire. The statements and questions are listed in Table 2 [12]; they are similar to the ones reported in [2, 4, 5, 9]. In addition, the students were asked to justify their answers/scores and to write a short essay regarding the pros and cons of blended laboratories based on the HELP kit.

Fig. 6 presents students' responses to the 9 points of the questionnaire listed in Table 2 [12]. For questions # 1, 3–5 and 8, only values chosen by students were presented. The students' feedback was very positive and will be detailed below. In general, students found the HELP kit easy to use; they quickly became familiar with the HELP kit through a tutorial class and a User Guide posted on the HELP platform. The most important advantage highlighted by students was the flexibility resulted from having the laboratory kit at home, over the entire semester. This way, they were able to spend more time preparing their assignments, familiarizing themselves with the measurement equipment without any time constraints. Other features appreciated by students were the HELP kit compactness, portability and ease of use, as compared to bulky standard laboratory equipment. The students encouraged the idea of introduction the HELP kit to several other courses; this way, they only need to familiarize themselves with the equipment once and they can also continue working on previous projects. Three students reported using the HELP kit to prepare projects for other courses or to develop personal projects. With one exception, the students found that the HELP kit contributed to their learning and increased their interest in analog electronics. Seven out of nine students found the homework assignments given to the HELP group more difficult to complete than the homework assigned to the reference group because they had to build and debug the circuits on the breadboard (the latter involved circuit analysis solely through simulations). Even so, all students within the HELP group declared that their homework was challenging but enjoyable and rewarding.

Table 2. HELP KIT evaluation questionnaire [12].

Question no.	Statement/Question
1[a]	The HELP kit was easy to use
2[b]	Did you encounter any difficulties during the experiments?
3[a]	The Brief User Guide was useful.
4[a]	The HELP kit was more suitable than standard laboratory equipment.
5[a]	Using a take-at-home HELP kit throughout an entire semester was useful.
6[b]	Did you use the HELP kit to other classes/projects?
7[b]	Do you consider advisable to extend the use of HELP kit to other classes?
8[a]	The use of HELP kit favours the assimilation of analog circuits analysis and design methodologies.
9[c]	From the discussions with your colleagues who did not receive the HELP kit and had homework assignments that had to be solved solely through simulations, estimate which of the two forms of the homework assignments was easier to execute: Board implementation and characterization through measurements or circuit design and characterization through simulations.

[a] Students had to choose a value between 1 (strongly disagree) and 10 (strongly agree).
[b] YES/NO questions.
[c] Students had to choose: Board implementation was Easier (BE), Same Difficulty (SD), or Board implementation was Harder (BH).

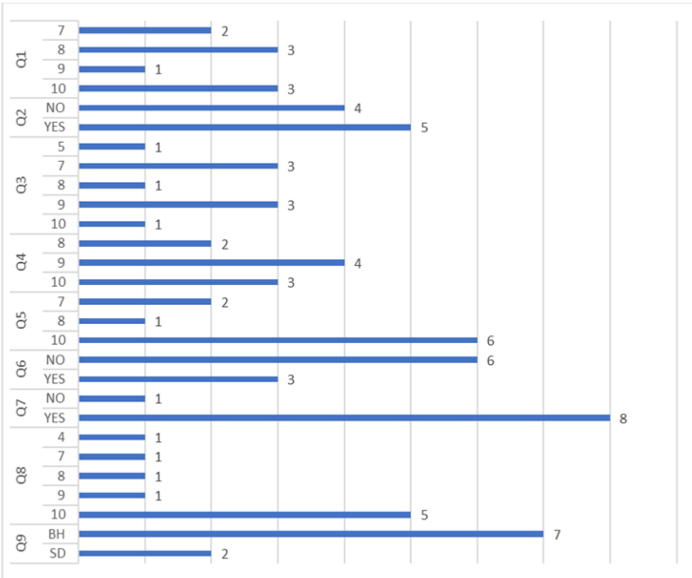

Fig. 6. Statistics of Students' responses to the questionnaire listed in Table 1.

5.2. Comparative analysis of academic results for the HELP and "Reference" groups of students

Let us analyze comparatively the academic performance of the two groups of nine students in this study – the HELP group (students who were randomly selected to undertake the SAIC labs following the blended approach based on the HELP kit) and the "reference" group (students who undertook only traditional, on-campus, lab classes). Fig. 7 presents the statistics of grades obtained by both groups at SAIC, for their lab tests and homework and for their written exam. The blue boxes correspond to results obtained by the HELP group, while the green boxes show results obtained by the "reference" group.

It indicates that the HELP group obtained significantly better grades for their lab tests & homework, with the median value almost 2 points (out of 10) higher than the "reference" group. Somewhat surprisingly, the same situation occurred for written exam grade.

The performance of the 18 students monitored within this study was analyzed for two other courses: Microprocessors Architecture and Optoelectronics. For these courses the lab classes were held exclusively on-campus, following traditional setups. At Microprocessors Architecture, the HELP group had a median value of the grades 0.5 points higher than the "reference" group, but the same average. At Optoelectronics, both groups had the same median value, but the HELP group had an average value 0.66 points larger compared to the "reference" group.

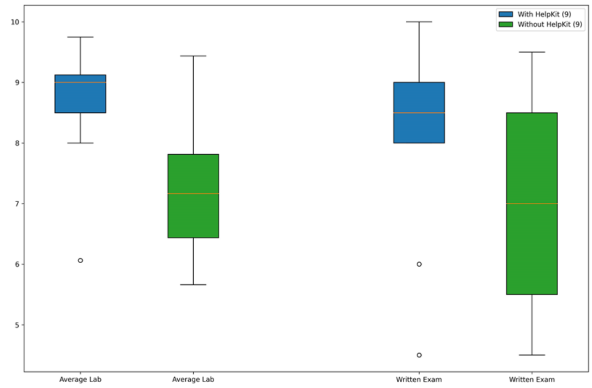

Fig. 7. A summary of students grades at SAIC course.

These results suggest that the blended approach to lab classes, with the HELP kit available to each student for the entire semester, contributed to improving the overall academic performance of the HELP students, compared to their "reference" colleagues.

6. Conclusions

This paper presented an affordable and easy-to-use laboratory kit and platform that allows students to perform at-home a wide range of experiments on electronic circuits. The HELP kit was used to implement a blended approach to laboratory classes on Systems with Analog Integrated Circuits, for third-year BSc. Students. The main idea of this approach is to combine on-campus laboratory sessions with at-home experiments performed individually by each student as homework. This way, students can enjoy the advantages of both on-campus and at-home experimental work while avoiding most of their limitations.

On the one hand, the HELP environment supports active learning, with students having practical, constructive, industry-relevant learning experiences by undertaking individual laboratory work off-campus using equipment similar (if simpler) to standard laboratory equipment. Also, the at-home experimental activity is no longer time limited and mistakes can be identified and fixed without undue pressure from peers and teachers. Also, by working individually – even if making use of the remote support available – students gain confidence in their ability to prototype electronic circuits. Finally, students get used to planning and managing their work, and to documenting and presenting experimental results. On the other hand, on-campus classes ensure students develop competences in analyzing and characterizing electronic circuits by using standard lab equipment and that they enhance their team-work abilities.

An administrative unit of 18 third-year students was split randomly in two equal-size groups, one that had only traditional on-campus lab classes while the other nine students were given HELP kits and followed the proposed blended on-campus and at-home approach for their lab classes. All students received end-of-semester marks for both laboratory activity (as an average of four tests and homework completion) and a written exam (solving four problems on circuit analysis). The group that used Help kits performed substantially better than their counterparts, both in respect to laboratory – average lab mark almost two points (out of ten) higher – and written exam – average exam mark over one point higher. These results indicate that the blended on-campus and at-home approach to laboratory classes helped improve the overall learning experience for students, with positive impact not only on their lab performance but on their understanding of electronic circuits, as well.

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