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Portable Laboratory for Electrical Engineering Education: The LAB-VEE Ecosystem Developed in Latin America and the Caribbean

Ing. Reymi Then, Universidad Tecnológica de Santiago

A young professional passionate about research, technologies and their teaching. From a very early age, he presented a high interest and understanding of engineering, starting studies and technical work in electronics in 2002. In 2004 he began to study electronic engineering at the Technological University of Santiago (UTESA) and in 2019 he coursed a master's degree in Mathematics at his Alma Mater.

His working experience started back in 2002 and over the years he had the opportunity of getting involve in different technological areas, such as: appliance repair, telecommunications and internet, biomedical, design and construction of electronic equipment and education in engineering and technologies. Since 2014, he works as an Engineering Professor and Researcher at the Technological University of Santiago. In addition, he has also been coordinating the engineering faculty as well in the university.

Since 2019 he has been a member of the National Research Career, and the GITECI-UTESA Research Group since 2016. He is also a member of the Scientific Advisory Council and Reviewer of the UTESA Engineering Journal since 2018. In addition, joins in 2022 the Smart Adaptive Remote Labs Research Group of the Latin American and Caribbean Consortium of Engineering Institutions (LACCEI).

Throughout his professional life, he has been publishing articles, and participating as a speaker in both national and international conferences on different research topics related to engineering education and the relevance of the use of appropriate tools for it.

Reymi Then is the ideologue and Co-founder of LAB-VEE Educational TechMakers, where he is currently responsible for the design and production of new technologies, hardware design and production, as well as the design and production of academic content.

Dr. Maria M. Larrondo-Petrie, Florida Atlantic University

Dr. Larrondo Petrie has a Ph.D. in Computer Engineering and is a Professor in the College of Engineering and Computer Science of Florida Atlantic University. She is the Executive Director of LACCEI (Latin American and Caribbean Consortium of Engineering Institutions, a Titular Member of the Pan-American Academy of Engineering, and a member of the ASEE International Activities Committee. She is a Lifetime Senior Member of IEEE and serves on multiple IEEE Standard Development Working Group on behalf of the IEEE Education Society. She is a registered International Professional Engineering Educator in the ENTER International Registry and ranked Level 5, Engineering Education Researcher.

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Abstract

The need for options that allow the quality of education to be guaranteed even outside educational institutions has intensified in the last 3 years due to the COVID-19 pandemic. In the case of engineering, several universities have initiated or increased efforts to mitigate the effects resulting from students taking electrical engineering classes from their homes without access to laboratories. Thanks to this, remote laboratories have been created that allow students to conduct experiments from their homes. Other universities have been working on the creation of portable laboratories that students can take home and conduct experiments as if they were in a traditional laboratory.

In this article, we present in detail the process carried out by a group of researchers from a university in the Dominican Republic for the creation of a portable electrical engineering laboratory that incorporates many the necessary equipment for a laboratory of this type. The creation of this laboratory emerged as a Research, Development and Innovation (R&D&I) project that was financed in the period 2018-2021 by the Ministry of Higher Education, Science and Technology (MESCyT) in collaboration with the Korea Advanced Institute of Science & Technology (KAIST) and the Korea International Cooperation Agency (KOICA) with an approximate budget of US$103,000.

The interest of the research team was to create equipment that would complement or replace most of the equipment used in an electricity laboratory and that would be low-cost. With the arrival of the pandemic, a redesign was carried out, becoming a portable laboratory that students can transport in their backpacks and at a lower cost than the existing options on the market. To date, it has received 2 injections of capital totaling more than US$28,000 from banking and governmental institutions, and recently the research team has been approved for more than US$200,000 to continue research and development in the field.
The production cost is around US$250 and is expected to decrease further. To date, 3 professors, 10 students, and a company have participated in this project. A company called LAB-VEE Educational TechMaker has been created for commercialization and an LMS with didactic content. The LMS was implemented in 2021 by a school in the country, with more than 60 students taking classes, having access to only theoretical content. A study was conducted on this implementation to measure the level of learning of these students compared to others who studied in a traditional way, and recently a university in the country has implemented LAB-VEE to conduct a study that will allow them to know its impact on the academic performance of university students.

Introduction

Latin America and the Caribbean share many similarities, from cultural, political, and educational to economic aspects [1]. The Dominican Republic, as a Caribbean country in the process of development, faces considerable educational and economic difficulties, and the effects of this reality directly impact STEM education, mainly because alliances between academia, the private sector, and the government are required to ensure the best inputs and practices [2], which translates into investments that are significant for the budget available to educational institutions. This fact has prevented educational centers such as schools, technical institutes, polytechnics, and universities, both public and private, from effectively implementing STEM programs throughout the national territory, as equipping a single laboratory represents a significant investment [3] and [4], and the obsolescence time of many of these equipment's is relatively short, however, they are essential to guarantee the training of young people in STEM areas [2].

In the case of schools, it has not been possible for the Dominican Republic to establish a plan that allows for the massive and consistent incorporation of STEM contents into basic and middle education, despite several efforts to steer national education towards offering the competencies that this methodology provides [5]. For the public sector, the greatest results achieved are for polytechnic high schools, which, thanks to strategic alliances with sectors such as the Catholic Church or other institutions, have managed to establish policies, agreements, educational models, and budgets that have guaranteed for decades their status as referents of basic education in the country [6]. However, the operating costs are such that it has not been possible to massify this model throughout the national geography, leaving this educational model available only to students residing in a small handful of provinces.

Regarding private basic education, a considerable percentage of schools have incorporated STEM subjects and laboratories for both basic and secondary education in recent years [7], offering their students, in most cases, programming, robotics, and computer classes, which increasingly incentivize and/or force other schools and educational sectors to venture into these contents and not disappear or fall behind [8].

On the other hand, both public and private universities have lagged in the incorporation of engineering programs, and their case is like that of public education, where only in the main provinces of the country are engineering programs offered, and not in all universities or campuses [9]. For those that have opened programs in this faculty, they have had serious difficulties both in guaranteeing the maintenance of equipment, as well as in replacing it when necessary. Two factors have influenced this, namely, the low number of students studying these programs, which makes them unprofitable, and the low capacity of universities to acquire new equipment [10], due to the low profitability of these programs.
Therefore, based on this context, an initiative has been worked on within the Technological University of Santiago, UTESA, called LAB-VEE Educational TechMakers, which is funded by MESCyT, KAIST and KOICA, as well as the Banco Popular Dominicano, to develop equipment, resources, and contents that allow for mitigating the problem of the cost of STEM laboratory equipment for educational centers in the Dominican Republic, both at the level of basic education and technical and university education. So, in this article, the developed solution, the process carried out, the results obtained, faced problems, and future actions of the mentioned project will be presented.

The proposal

In 2017, the Ministry of Higher Education, Science and Technology (MESCyT) of the Dominican Republic, together with the Korea International Cooperation Agency (KOICA) and the Korea Advanced Institute for Science and Technology (KAIST), opened the call for "Human Resource Development Project in Engineering, through the establishment of an R&D collaboration system between Higher Education Institutions and companies to promote science and technology in the Dominican Republic". Several universities and companies in the country participated in the launch of this call, from which multiple agreements were formed between national researchers and entrepreneurs, including the research team from the Technological University of Santiago, UTESA, which entered into an agreement with the company OPEX SRL.

UTESA is the largest private university in the Dominican Republic, with a presence in 8 provinces and an enrollment of over 50,000 students. OPEX SRL, on the other hand, is a company dedicated to training employees in specific competencies required by companies. Together, they submitted a proposal to develop equipment that could replace the traditional equipment of an electricity/electronics laboratory, which was low-cost, easy to use, and maintained a realistic interface. In 2018, the approved projects were announced and out of over 100 proposals, only 15 were approved, one of which was the UTESA-OPEX consortium with an approved budget of over US$103,000.00 and a 2-year execution time. This project was called LAB-VEE Educational TechMakers, and a laboratory equipped with everything necessary to achieve the proposed objectives was set up for its development. The university team consisted of 3 research professors, 3 research assistants, and a total of 6 interns; the company team consisted of 1 project leader, 1 software developer, and 1 LMS administrator.

- Specifically, the goals of the research team were:
- Develop a hardware that would serve as a workstation and incorporate all the necessary instruments and equipment for an electrical/electronic laboratory.
- Develop a training board that could be placed on the workstation so that students in the course could study with its embedded devices.
- Develop a software that would allow communication between the workstation and the computer to allow use of the equipment, with great emphasis on achieving the most realistic GUI possible.

After the project was started and the pandemic arrived, the research team set 3 more goals, which were:

- Redesign the hardware to make it completely portable so that students could carry it with them in their backpacks.
- Develop educational content to offer technological education to basic education students.
- Enable an LMS to host the educational content.

To achieve these objectives, the consortium maintained a constant work schedule, for which tasks were distributed based on each team's competencies. For the UTESA team, which was the proposing and researching team, the task of leading the entire process carried out during the project's execution was assigned, as well as the management of the financial part and report performance to MESCyT, KOICA, and KAIST. In addition to these administrative tasks, the university team was also responsible for the development of electronic hardware, electronic firmware, practice cards, design and production of encapsulated parts, editing of scripts and animations for educational videos, and drafting step-by-step questionnaires and tutorials for student practices.

On the other hand, the OPEX team oversaw the development and administration of a Learning Management System (LMS) where the educational contents developed by the research team could be placed. Similarly, the company oversaw developing a program for PC that served as an interface for the use of the instruments integrated into the electronic hardware (workstation). The commercialization of the developed product was also part of the responsibilities delegated to the company.

The project had a plan to be executed in 2 years, however, due to the arrival of the pandemic and with it the confinement, an extension of 3 more months was granted to recover the time elapsed without working effectively on the scheduled tasks. Once the deadline for the results delivery arrived, it was possible to fully comply with the objectives proposed in the original proposal, even with the delivery of the new objectives that the research team added from the arrival of the pandemic.

Results obtained

As specified earlier, the project arose as an initiative of a university professor who was interested in developing a workstation that integrated as many of the necessary equipment in an electricity/electronics laboratory as possible and that was economically viable, even for institutions with limited resources. To achieve this, the UTESA-OPEX consortium embarked on the development of several technologies and resources that enabled the functioning of all the involved parts in a unified way as an educational ecosystem. Therefore, at the end of the project development time, the research team had managed to develop a workstation, a practice board, an LMS platform with educational content, and an application for the interface with the workstation.

Workstation:

The workstation is the hardware that has been developed to incorporate the electronic boards that enable the functionality of each of the laboratory equipment that this workstation incorporates as well as the communication of each of these with the application software, through which it is possible to interact with the equipment, and also serves as a setting to place the practice boards that students use in each subject or to place breadboards and assemble circuits in more detail.

Figure 1: Workstation

Among the equipment incorporated in the workstation:

- 2 independent DC power sources, which can have the output voltage established from 0V to 10V with a resolution of 10mV. Similarly, the maximum current that can be delivered by these power sources can be set to values between 0A and 1A with a resolution of 10mA.
- 1 signal generator, which can produce sine, square, triangular, and continuous waveforms. This signal generator can have output voltages established from 0V to 5V, with a resolution of 10mV. The frequency of the signal can also be set to a range of 0.1Hz to 100KHz.
- 1 digital multimeter, with which it is possible to make DC voltage (VDC) measurements with a resolution of 0.1mV, DC current (ADC) with a resolution of 1mA, electrical resistance (Ω) up to values of 1MΩ, and continuity.
- 3 independent voltmeters, with which, in addition to the multimeter, it is possible to monitor 3 different voltages with a resolution of 0.1mV.
- 3 independent ammeters, with which, in addition to the multimeter, it is possible to monitor 3 different currents with a resolution of 1mA.
- 1 “2-input” oscilloscope, this allows viewing the shape of electrical signals and configuring the parameters to improve its visualization. This oscilloscope has a sampling rate of 10M samples/seconds (10MSPS), allowing viewing signals up to 300KHz.
- 1 “8-bit” logic state generator, with which it is possible to generate binary counts, binary combination sequences from truth tables and Karnaugh maps.
- 1 “8-bit” logic state analyzer, with which it is possible to sample binary pulse trains up to 1MHz.

Practice boards:

The practice boards consist of a pre-assembled plastic housing with embedded electrical devices that perfectly fits the work area of the workstation. These boards have been designed to provide students with a practical, less abstract experience with a high degree of realism in terms of the usefulness of the knowledge provided. In each board, input modules, processing modules, and output modules have been incorporated that together allow creating fully functional and interesting circuits, while at the same time allowing measurements and analysis of their operation, as well as the variables that enable it.

Two practice boards have been developed, one for DC electrical circuits and the other for logic circuits.

In the DC electrical circuit board, several modules have been incorporated, which are:

• 1 module with 12 fixed resistors.

• 1 module with a straight displacement potentiometer.

• 1 module with a rotary potentiometer.

• 1 module with a light-dependent resistor (LDR).

• 1 module with a temperature-dependent resistor (NTC TDR).

• 1 module with a rocker switch.

• 1 module with a push button.

• 2 modules with one bulb each.

• 2 modules with one LED each.

• 1 module with 1 buzzer.

• 1 module with an electromagnet.

• 1 module with a propeller motor.

• 1 module with a wheel motor.

• 1 module to vary electrical power from a resistor value.

• 1 voltage comparator module.

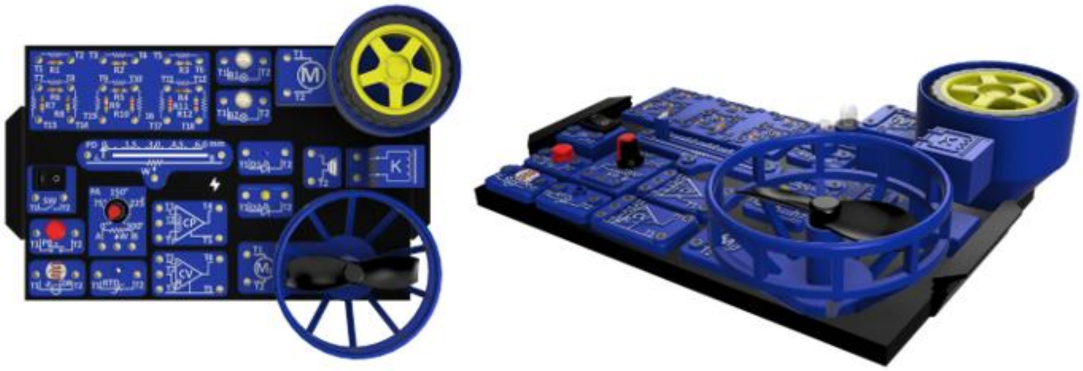

Figure 2: DC Electrical Circuit Practice Board

For the logic circuit board, a cutting-edge and simplified practice board has been developed that allows students to interact with modules that are not parallel communication, but to allow their use under this communication protocol, the data supplied by this has been decoded so that the student can have it in binary and produce logic circuits from truth tables, thus controlling output devices. This board has also been provided with a space for the placement of project modules that come with a defined theme, for example, a traffic light, an elevator, or an airplane, which students must design a logic with the gates on the practice board to achieve the required functionality.

This logic circuit practice board incorporates:

• 1 module with an infrared distance sensor.

• 1 module with a binary counter.

• 1 module with an infrared remote control receiver.

• 1 module with a light dependent resistor (LDR).

• 1 module with a touch switch.

• 1 module with a scale for weighing objects.

• 1 module with an RFID receiver.

• 1 module with a numeric keyboard.

• 20 NOT gates.

• 16 AND gates.

• 16 OR gates.

• 4 XOR gates.

• 4 LATCH.

• 1 module with a buzzer.

• 1 module with 1 LED.

• 1 module with a 2-digit display.

• 1 space for placement of a project module.

Figure 3: Practice board for logic circuits

Both the workstation and the practice boards have undergone several updates from their first design in 2019. Figure 4 shows the first version of the workstation and the first practice board. The design of these plastic parts was developed by the research team using Fusion360 3D design software and manufacturing these parts in the university using 3D printing technology.

The use of 3D printers has been a great help for the development of this project, as it has allowed for prototyping in extremely short times, as well as not relying on a third party to perform these tasks, and if the encapsulations were made by plastic injection, the associated costs would be unsustainable for the project. In the same way, 3D printing has allowed producing the final product to be delivered to customers with a very acceptable quality and viable cost.

The software/application:

In order for the students to interact with the laboratory equipment embedded in the workstation, it was necessary to develop an application used as a graphical interface and also maintained the sensation of working with a real equipment, so that when the students interact with a physical equipment in real life situations, they can feel completely related to it and it’s easy to use.

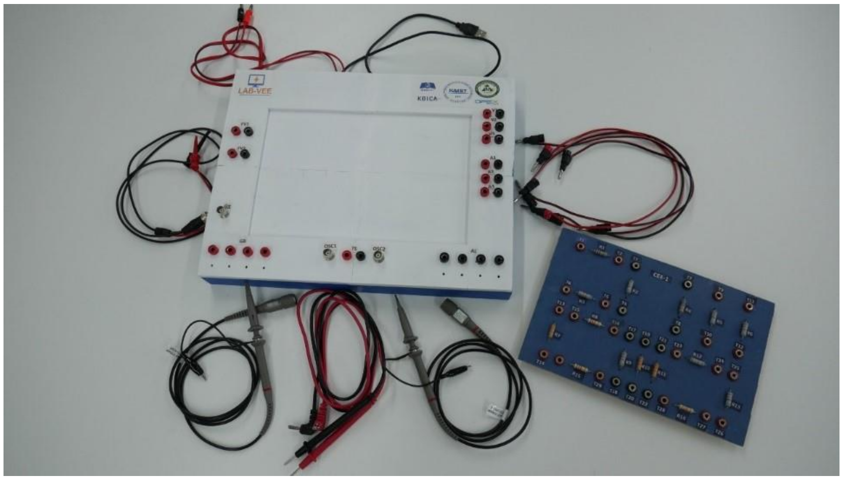

Figure 4: Old version of the workstation and the DC electrical circuit practice board

For this reason, the application has a realistic interface, as well as realistic movement and animation when the buttons of each equipment are used. In Figure 5, you can see the dashboard of this application, which was developed in Python and the graphical representation of each equipment was designed and rendered to maintain a great touch of realism. From the dashboard, you just must click on one of the instruments to open its interface and allow its use.

In addition to opening to the laboratory equipment, the application also allows access to the LAB-VEE website, the LMS, help, and other resources.

Figure 5: Instruments Software Application

Educational Platform (LMS):

As a Learning Management System (LMS), a personalized version of Moodle has been used to host the educational content and carry out the pedagogical and didactic process of the subjects taught by the LAB-VEE ecosystem. This LMS can be seen in figure 5, where explanatory videos (figure 7) have been incorporated into it, through which the theoretical content of the subject is transmitted to the students. After each explanatory video, a quiz (figure 8) has been placed that allows the student to identify the level of understanding achieved regarding the explained content, giving the option to repeat the video and the quiz if the student so wishes. In terms of the practical part, after the students watch the video and take the quiz, they are ready to put into practice the knowledge acquired using the workstation, the applications and the corresponding practice board for the course. To support the students in this practical part, step-by-step tutorials (figure 9) have been developed for each practice, which are fully illustrative and realistic, giving the students the appropriate accompaniment so that the level of confusion is minimum when creating a circuit. Similarly, to the explanatory videos for the practices, reflective questions (figure 10) have been developed that guide the students in the understanding they should be achieving throughout the steps of each practice, thus causing them to contextualize the physical phenomena that occur in each case and their understanding.

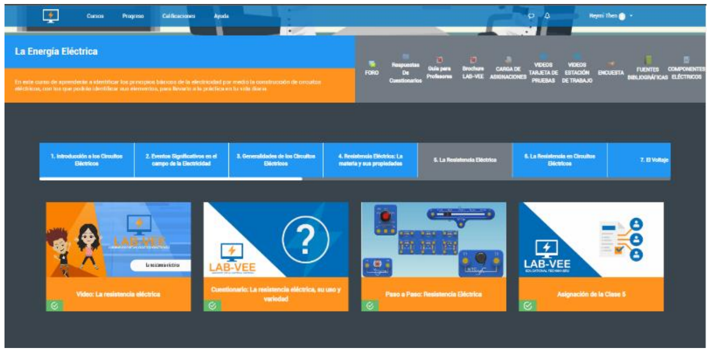

Figure 6: LAB-VEE LMS

The LMS allows students to have a high degree of autonomy in their study process, freeing the teacher from monotonous tasks and allowing them to make better use of their presence by providing support to students who need help. Additionally, students are awarded badges through the LMS based on their progress and completion of challenges. Similarly, this platform also allows for record keeping of each student's progress and the topics where they have faced difficulties.

The LMS was set up on Moodle taking advantage of the high flexibility that it offers when making updates or improvements to any content or resources that may need it, as well as its wide availability of interaction with other programs.

Figure 7: Explanatory video

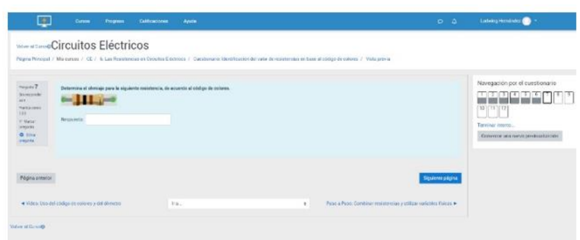

Figure 8: Quiz

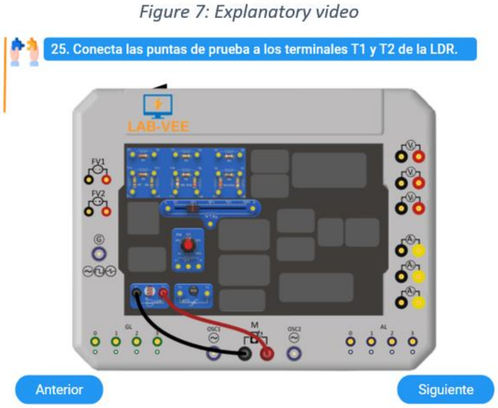

Figure 9: Step by step tutorial

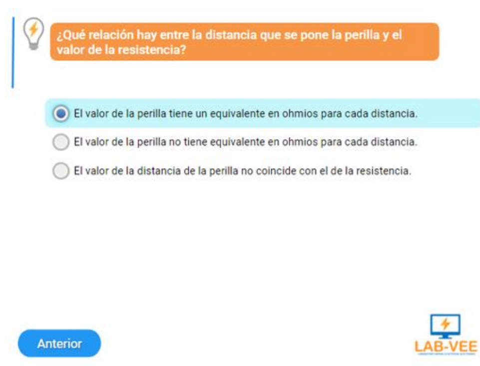

Figure 9: Reflection questions

LAB-VEE Educational TechMakers

Currently, there are several initiatives and companies seeking to supply equipment and software that can be used in electricity/electronics laboratories and facilitate their study. In the case of companies, we can mention:

- National Instruments (NI) with ELVIS, myRio, and myDAQ stations.
- Digilent with Analog Discovery Studio, Electronic Explorer, Analog Discovery, and OpenScope MZ.
- Festo Didactic's with FACET Electronics Training System and Virtual Instrument Package.
- De Lorenzo with TIME Electronic Boards.
- Analog Devices with ADALM2000.
- Red Pitaya with SIGNALlab 250-12 and STEMlab 125-14.
- MicroE with development boards and other training kits.

Other initiatives seeking to contribute to this problem from universities are:

- Rapid Analysis and Signal Conditioning Laboratory (RASCL) by Kansas State University.
- Labshare, led by the University of Technology Sydney (UTS), and is a joint initiative of the Australian Technology Network (UTS, Curtin, UniSA, RMIT, and QUT).
- LILA, developed at the University of Stuttgart and co-funded by the European Commission.
- UNILabs developed at the National Distance Education University in Madrid.
- Lab2Go, developed at the Carinthia University of Applied Sciences.
- ISILab developed by the University of Genoa.
- RwmLab developed by Western Michigan University.
- NetLab developed by the University of South Australia.
- PEMCWebLab developed by Brno University of Technology.
- iSES developed by Charles University of Prague.
- iLAB developed by Massachusetts Institute of Technology in collaboration with Microsoft.
- RemotElectLab developed by the University of Porto.
- VISIR developed by Blekinge Institute of Technology.
- ArPiLab developed by the Slovak University of Technology in Bratislava.
- LaboREM developed by Bayonne Technological University Institute.
- SEITI RMLab developed by Sidi Mohamed Ben Abdellah University.
- SARL developed by Florida Atlantic University.
- WebLab-Deusto developed by the University of Deusto.

As we can see, there are multiple teaching laboratory projects for electricity/electronics that have been developed in recent years, several of which have become companies. Regarding the initiative presented in this article, which was born at the Technological University of Santiago (UTESA), after completing the project development phase, in 2021, the process of establishing and formalizing LAB-VEE Educational TechMakers as a company began, with the intention of reproducing and commercializing the equipment and content that were developed. In that same year, the company participated in a Popular Impulse call sponsored by the Banco Popular of the Dominican Republic and aimed at small businesses. In this call, LAB-VEE was the winner of two awards, one for being the project with the most votes from the public and another for being selected as the contest's winning project. In total, for both awards, it received an amount greater than US$26,000. Similarly, the company has participated in technological fairs sponsored by governmental institutions, where the entrepreneurship has been recognized and awarded an amount greater than US$900 for its great innovation and social impact that implies its conception. The company has its website (www.labvee.com), as well as Instagram (labvee.rd), Facebook (lab-vee), and Youtube (LAB-VEE EduTech).

Between 2020 and 2021, a study was conducted on the implementation of LAB-VEE educational content for a group of high school students at a private school in the city of Santiago, Dominican Republic, compared to another group that only took the subject in a traditional way. This study was presented at The Latin American and Caribbean Consortium of Engineering Institutions (LACCEI) in 2021, revealing how the use of educational resources, in this case, only the theoretical ones in the educational ecosystem, contribute to the formation of students at this STEM education level [11]. This study has been continued in the 2022-2023 period, but this time incorporating practical exercises with the portable laboratory. In 2023, a university in the country is incorporating LAB-VEE in its electrical and electronics laboratories, where a study is also being carried out to determine its impact on the academic performance of university students.

Thanks to the participation in LACCEI, collaboration channels were created with a research team from Florida Atlantic University (FAU). This research team is working on the creation of remote laboratories called "Smart Adaptive Remote Labs" (SARL) and both teams are exploring the integration of technologies that have been developed separately and that promise to be a great complement now.

Currently, LAB-VEE has a selling price that represents a savings of between 30% - 70% compared to other similar products. This has been achieved because all the resources have been developed from scratch by the research team and the costs have been covered with the assigned budget, which eliminates the payment to third parties for the development or use of their properties. Similarly, a factor that has allowed cost reduction is the manufacturing of plastic parts (cases) using 3D printing. And not least, the electronic design has implemented an architecture that in its functionality/cost relationship does not represent an extraordinary investment.

Challenges encountered

During the development of the project, various challenges were presented that required the resilience of the research team, challenges faced where administrative, technical, and social. Concerning administrative challenges, those of greater significance were the irregularity in the flow of disbursements for the project's execution, this impacted different aspects of the project's development, on the one hand, it made the execution of the proposed schedule impossible and on the other hand, it weakened the motivation of investigators and research assistants.

As for the technical challenges, there are the problems inherent in the type of technology to be developed. For example, in electronics, it was necessary to categorize several electronic devices to identify the one that best suited the design requirements and maintained a minimum cost. In the same way, it was necessary to solve problems with microcontrollers due to the electromagnetic noise produced by switched sources.

Regarding the social challenges, there is the reality that in our culture as a developing country, there is a lack professional personnel dedicated to research and development, which directly affected us at times when professional personnel was required to be substituted or incorporated into the project.

Another problem that has affected us in a great manner, is the shortage of semiconductors that the world is currently experiencing after the COVID-19 pandemic. Now there is no stable availability of parts and much less variety compared to previews years.

In conclusion, these challenges have tested the resilience of the research team but have not defeated them. Many of these have been overcome and others are still being worked on and looking forward to the next challenges that will surely come.

Conclusion and future actions

Currently, other curricula and resources are being created to incorporate 4 more courses into the LAB-VEE ecosystem so that a complete educational program can be supplied to K12 students. The contents to be covered in these new curricula are Microcontrollers and programming languages, Computing and automation, 3D printing, and Robotics.

In parallel, the LAB-VEE and SARL research teams are joining forces to create a portable laboratory at a cost that can be purchased by students in developing countries, and another version to be integrated with SARL to serve as a remote laboratory to be accessed by students from anywhere in the world.

On the other hand, the LAB-VEE research team is working on the development of an Intelligent Tutor System (STI) for which they have a grant of more than US$200,000 from the Ministry of Higher Education Science and Technology of the Dominican Republic, through the National Fund for Innovation and Scientific and Technological Development (FONDOCYT), with which they aim to identify the impact that this can have on electrical engineering students when studying under their tutorship. This development is an advantage for LAB-VEE, as once the research is completed, if the results are promising, the LAB-VEE LMS will be configured under this STI. It is expected to become a great resource that will be available for all international education systems.

References

[1] Álvarez Leguizamón, Sonia. “Trabajo y producción de la pobreza en Latinoamérica y el Caribe: estructuras”, discursos y actores. 2005.

[2] Escobar, Ismael Mauricio Duque, et al. "Educación STEM en educación básica: estudio de caso en dos países, Colombia y República Dominicana." Encuentro Internacional de Educación en Ingeniería (2015).

[3] Guerrero Sierra, Diana Paola. "Propuesta de un aula steam bajo el enfoque industria 4.0 en la UFPS." (2021).

[4] Felder, R., and Rebecca Brent. "Cómo se presenta la educación en ciencia tecnología ingeniería y matemáticas (STEM) en cinco años o antes?" Teaching and Learning STEM (2016): 1-6.

[5] Valeirón, Julio Leonardo. "La educación dominicana ante un gran reto." Revista de Investigación y Evaluación Educativa 1.1 (2014): 38-56.

[6] Javier, Luz Verys Ramón, and Thelma Camarena. "Creación de comunidades de aprendizaje con miras a potenciar las competencias docentes en los politécnicos del Distrito Educativo 05-03 RD." 08va. Edición: 151.

[7] Lizardo, Jefrey. “Evaluación de costos de la educación básica en la República Dominicana.” Proyecto EDUCA/FLACSO/PUCMMCIED-HUMANO, auspicio PREAL, Santo Domingo, 2010.

[8] Amargós, Oscar, and Magda Pepén Peguero. "Educación secundaria y la desigualdad social en República Dominicana." ESTADO DE LA EDUCACIÓN SECUNDARIA EN AMÉRICA LATINA Y EL CARIBE (2020): 139.

[9] MEJÍA, Tirso. "Las reformas de la educación superior en la República Dominicana." IESALC/UNESCO, Caracas (2003).

[10] Informe Nacional República Dominicana, "Informe Nacional Santo Domingo, R.D.," agosto de 2016.

[11] Marte Zorrilla, Edwin, and Reymi Then. "An Analysis in Student Learning Achievement in Electrical Concepts Using a Guided Curriculum." In Proceedings of the 19th LACCEI Multiconference,” LACCEI, 2021.

[12] Warren, S., Dong, X., Sobering, T.J., Yao, J., A Rapid Analysis and Signal Conditioning Laboratory (RASCL) Design Compatible with the National Instruments myDAQ Platform,” in Proceedings of the 2011 ASEE Conference & Exposition, American Society for Engineering Education, 2011.

[13] Yan, Y. Adams, R.D., Yanik, P.M., Jack, H., Ritenour, A. Karayaka, H. B., “BYOE: Individual Lab Kit Options for Analog and Digital Circuits Suitable for In-class or At-home Experiments,” in Proceedings of the 2021 ASE Annual Conference, ASEE, 2021.

[14] Lowe, Davit, et al. "LabShare: Towards a national approach to laboratory sharing." Proceedings of the 20th Annual Conference for the Australasian Association for Engineering Education. The School of Mechanical Engineering, University of Adelaide, 2009.

[15] T. Richter, Y. Tetour, and D. Boehringer, “Library of Labs - A European Project on the Dissemination of Remote Experiments and Virtual Laboratories,” in 2011 IEEE International Symposium on Multimedia, 2011, pp. 543–548.

[16] J. Saenz, J. Chacon, L. De La Torre, A. Visioli, and S. Dormido, “Open and Low-Cost Virtual and Remote Labs on Control Engineering,” IEEE Access, vol. 3, pp. 805–814, 2015.

[17] M. Kalúz, L. Čirka, R. Valo, and M. Fikar, “ArPi Lab: A low-cost remote laboratory for control education,” in IFAC Proceedings Volumes (IFAC-PapersOnline), 2014, vol. 19, no. 2013, pp. 9057– 9062.

[18] M. Chirico, A. M. Scapolla, and A. Bagnasco, “A new and open model to share laboratories on the internet,” IEEE Trans. Instrum. Meas., vol. 54, no. 3, pp. 1111–1117, 2005.

[19] J. A. Asumadu et al., “A Web-Based Electrical and Electronics Remote Wiring and Measurement Laboratory (RwmLAB) Instrument,” IEEE Trans. Instrum. Meas., vol. 54, no. 1, pp. 38–44, Feb. 2005.

[20] Z. Nedic and J. Machotka, “Remote Laboratory NetLab for Effective Teaching of 1 st Year Engineering Students *,” Int. J. Online Eng., vol. 3, no. 3, pp. 1–6, 2007.

[21] P. Bauer, V. Fedák, and O. Rompelman, “PEMCWebLab-Distance and virtual laboratories in electrical engineering: Development and trends,” Power Electron. …, pp. 2354–2359, 2008.

[22] F. Schauer, F. Lustig, J. Dvoák, and M. Ovoldová, “An easy-to-build remote laboratory with data transfer using the Internet School Experimental System,” Eur. J. Phys., vol. 29, no. 4, pp. 1–13, 2008.

[23] V. J. Harward et al., “The iLab shared architecture: A web services infrastructure to build communities of internet accessible laboratories,” in Proceedings of the IEEE, 2008, vol. 96, no. 6, pp. 931–950.

[24] N. Sousa, G. R. Alves, and M. G. Gericota, “An Integrated Reusable Remote Laboratory to Complement Electronics Teaching,” IEEE Trans. Learn. Technol., vol. 3, no. 3, pp. 265–271, Jul. 2010.

[25] M. Tawfik et al., “Virtual Instrument Systems in Reality (VISIR) for Remote Wiring and Measurement of Electronic Circuits on Breadboard,” IEEE Trans. Learn. Technol., vol. 6, no. 1, pp. 60–72, Jan. 2013.

[26] M. Kalúz, L. Čirka, R. Valo, and M. Fikar, “ArPi Lab: A low-cost remote laboratory for control education,” in IFAC Proceedings Volumes (IFAC-PapersOnline), 2014, vol. 19, no. 2013, pp. 9057– 9062.

[27] F. Luthon and B. Larroque, “LaboREM - A Remote Laboratory for Game-Like Training in Electronics,” IEEE Trans. Learn. Technol., vol. 8, no. 3, pp. 311–321, 2015.

[28] O. Zine, M. Errouha, O. Zamzoum, A. Derouich, and A. Talbi, “SEITI RMLab: A costless and effective remote measurement laboratory in electrical engineering,” Int. J. Electr. Eng. Educ., p. 002072091877504, May 2018.

[29] Weinthal, Charles Perry, Maria M. Larrondo-Petrie, and Luis Felipe Zapata-Rivera. "Academic Integrity Assurance Methods and Tools for Laboratory Settings." 2019 IEEE Frontiers in Education Conference (FIE). IEEE, 2019.

[30] Tulha, Carinna Nunes, Marco Antonio G. Carvalho, and Leandro N. de Castro. "LEDA: A Learning Analytics Based Framework to Analyze Remote Labs Interaction." Proceedings of the Ninth ACM Conference on Learning@ Scale. 2022.