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Use of free software with low-cost hardware for the development of experiential learning

Utilización de software libre con hardware de bajo costo para el desarrollo del aprendizaje experiencial

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Abstract

This article aims to propose the use of low-cost hardware with free software to achieve experimental learning in engineering students. The hardware is implemented using the Arduino platform and the free Scilab software, which is useful for carrying out engineering studies. To control the Arduino, Xcos/Scilab is used through a hardware remote library. This graphical programming environment allows the development of virtual laboratories. As results, it should be highlighted that the active participation of students, motivation for the career and the development of collaborative learning and self-learning are achieved. The research was developed in the Electrical Engineering major, for a sample of 60 third-year students who took the subjects of Power Electronics and Electrical Circuits in the courses between 2020 -2022, of the Electrical Engineering major, which represent 86% of the year's enrollment, evaluating its results through the calculation of absolute and relative frequencies, concluding that carrying out laboratory practices using the proposed methodology makes it possible to improve the results of the teaching-learning process of the students.

Keywords: Active learning, Arduino, Power electronics, Scilab, Teaching-learning process, Virtual laboratories.

Resumen

Este artículo tiene como objetivo proponer el empleo del hardware de bajo costo con software libre para lograr un aprendizaje experimental en estudiantes de ingeniería. El hardware se implementa mediante la plataforma Arduino y el software libre Scilab el cual es útil para realizar estudios de ingeniería. Para el control del Arduino, se utiliza Xcos/Scilab a través de una biblioteca de remota de hardware. Este entorno de programación gráfico, permite el desarrollo de laboratorios virtuales. Como resultados deben destacarse que se logra la participación activa de los estudiantes, la motivación por la carrera y el desarrollo del autoaprendizaje y el aprendizaje colaborativo en los estudiantes. La investigación se desarrolló en la carrera de Ingeniería Eléctrica, para una muestra de 60 estudiantes de tercer año que cursaron las asignaturas de Electrónica de Potencia y Circuitos Eléctricos en los cursos comprendido entre 2020 -2022, de la carrera de Ingeniería Eléctrica, los que representan el 86 % de la matrícula del año, evaluándose sus resultados a través del cálculo de las frecuencias absolutas y relativas, concluyéndose que la realización de las prácticas de laboratorios mediante la metodología propuesta posibilitan la mejora de los resultados del proceso de enseñanza - aprendizaje de los estudiantes.

Palabras clave: Aprendizaje activo, Arduino, Electrónica de potencia, Scilab, Proceso de enseñanza-aprendizaje, Laboratorios virtuales.

The occurrence of the COVID-19 pandemic created complex scenarios in educational systems for the development of the educational teaching process in a generalized manner due to various factors, characterized by the closure of educational centers and the necessary health measures to reduce infections. with little experience in the development of courses in the distance and/or blended modality.

In that sense, given the imminent needs to continue the teaching process, the search began, by educational institutions, for viable ways to continue the educational process.

According to the investigative works of the references [1,2] to achieve this objective, it is necessary to exploit the advantages offered by information and communications technologies (ICT) in the educational field, specifically in university teaching, for this it is necessary to use professional free software, which enhances the performance of theoretical - practical - experimental exercises for training and development of professional skills.

On the other hand, simulation software has a great impact on carrying out virtual laboratory practices, because as stated by the authors of the reference [3] they improve the preparation of students to respond to various problems and professional situations.

In this sense, emphasize that among the advantages that ICT offer in the distance training process, aspects such as availability of resources, ease of information and communication, access to resources from remote locations and provide improvements in work environments. [4]

In that order, in the contributions of [5 - 8] studies are carried out on the use of free software applied to the teaching-learning process in educational centers. These researchers emphasize the fact that the use of free software represents one of the main bases in the current educational environment as a scientific tool and at the same time the need to form an integral part of the curriculum.

An example of the above is that, as stated in [9 - 11], the Arduino hardware and software allows connecting electronic components to control real events, as well as expressing actions based on a C/C++ programming language. Arduino boards are affordable in cost and easy to use, making them suitable for educational and rapid development projects. They are based on microcontrollers with digital and analog inputs and outputs, as well as connectors to expand their functionality. The software is a free integrated development environment, its simplicity and low cost has driven widespread employment in the teaching of electronics, electrical circuits, automation and robotics. It has also made it possible for developers, teachers and students to explore creative ideas in an open-source environment.

Correspondingly, the authors of [12,13] have used the Arduino platform for didactic purposes, emphasizing the idea that it is necessary to continue increasing the demonstrations assisted by this type of educational tools which are useful in theoretical - practical - experimental demonstrations. by carrying out remote laboratories based on virtual teaching-learning environments, in which students can carry out practices, without being present in the same facility location.

According to references [7,14,15], Scilab includes a collection of mathematical functions and commands for mathematical modeling applied in electrical engineering.

Now, one of the most important topics taught in the Power Electronics subject are the models that represent the thermal behavior of semiconductors. Traditionally, the educational approach for this topic is based on a theoretical demonstration, based on physical foundations on semiconductors, heat transfer, electrical circuits and mathematical calculation. The integration of several disciplines, the level of attention to detail and a sequential process of how the phenomenon occurs, makes it particularly difficult for students to understand the full magnitude of the problem posed.

Therefore, it is necessary for students to experience the phenomenon from a real perspective, in order to develop new knowledge and skills.

On the other hand, according to [2] for practical purposes, simulation can be defined as an experiential instruction method that teachers use to imitate and replicate real scenarios, problems, procedures and develop skills to achieve the desired educational result.

For all of the above, the work presented has as a background the need to increase the hours dedicated to experimentation, so the objective of this research is to propose the use of low-cost hardware with free software to achieve experimental learning of the thermal behavior of the semiconductor junction through laboratories in engineering students, which will not only help improve the teaching-learning process but also the motivation of students for the career. For this, the Scilab software integrated with the Arduino hardware platform is used.

The research was developed in the Electrical Engineering program, for third-year students of the Technological University of Havana “José Antonio Echevarría”, CUJAE, and its results were evaluated based on structured interviews.

Materials and methods

In order to develop the objective of this research, it was necessary to verify the existing theoretical studies and search for the scientific knowledge accumulated around the development, evolution and improvement of the teaching-learning process of engineering, specifically the subjects of engineering. Power Electronics and Electrical Circuits in the Electrical Engineering career of the Technological University of Havana “José Antonio Echeverría”, CUJAE, as well as the use of simulation as a method of the teaching-learning process, the use of professional free software and the Arduino platform.

The study was based on a descriptive methodology in which the methods of the theoretical, historical - logical, analytical - synthetic, inductive - deductive and systematization levels were used, which allowed revealing the essential relationships of the object of study.

As an empirical level method, the structured interview was applied to know the students' opinions about the usefulness of the proposal to improve the teaching-learning process of the subjects of Power Electronics and Electrical Circuits.

The aspects to be considered in the interview, which are shown in the annex, focused on how the development of the proposal helped them increase their interest in the career, develop professional skills, as well as self-learning and collaborative learning, the theoretical-practical linkage, and the usefulness of the teaching materials developed for study.

The population was made up of 60 students of third-year who took the subjects of Power Electronics and Electrical Circuits in the courses between 2020 -2022, of the Electrical Engineering degree, which represent 86% of the year's enrollment.

As a statistical method, the calculation of absolute and relative frequencies was used for the processing and analysis of the information obtained in the interviews carried out. In addition, different department, methodological and year group meetings were held, the methodological work plans of the discipline of Electronics and Electrical Circuits were reviewed.

Results

The experimental laboratory proposal of this work is reflected within traditional laboratories, but with bases to enable remote work in the future. To do this, it is proposed to create a computer that works with GNU/Linux and runs the Scilab software through a Web interface. The laboratory hardware would be connected to this server running Scilab and the data acquisition functions in the Xcos would be run in preloaded scripts.

Proposals for experimental laboratory practices

The experimental laboratory is made up of several basic and indispensable elements, the entire system that makes up the experimental laboratory is low cost, compared to proprietary systems such as kits from the manufacturer Microchip. A simple diagram of the laboratory elements is shown in Figure 1.

To measure temperature, a thermocouple probe is used, fixed to the bipolar transistor housing. This probe is part of a traditional digital multimeter kit for commercial use, which makes its easy acquisition possible. Resistor R1 is responsible for controlling the current that circulates through the base of the transistor. In the case of the collector current, this will be the saturation current of the transistor, limited by the power supply. The power supply must be adjustable, not only the output voltage, it must also be able to set the maximum current it delivers.

The Arduino platform is connected by USB cable to the computer. Through this connection, the useful cycle (D) of the pulse width switching (PWM) of the transistor can be controlled. The Arduino microcontroller is controlled through signals via the USB cable generated from the Scilab software. In this way obtain control and the integrated graphics creation tool.

In figure 2 can see the development in control blocks in Xcos, of the control program in the graphical environment.

The “Board 1” block is responsible for configuring the serial connection port of the Arduino board. The square wave generator makes it easy to program the pulse width modulator (PWM), adjusting the switching period and duty cycle.

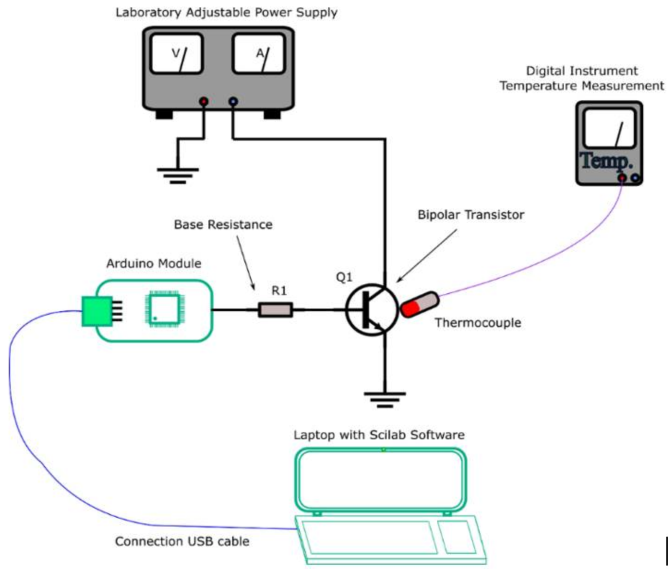

Figure 1. Simplified general diagram that describes the experimental laboratory to determine the thermal behavior in semiconductors. (Source: own self.)

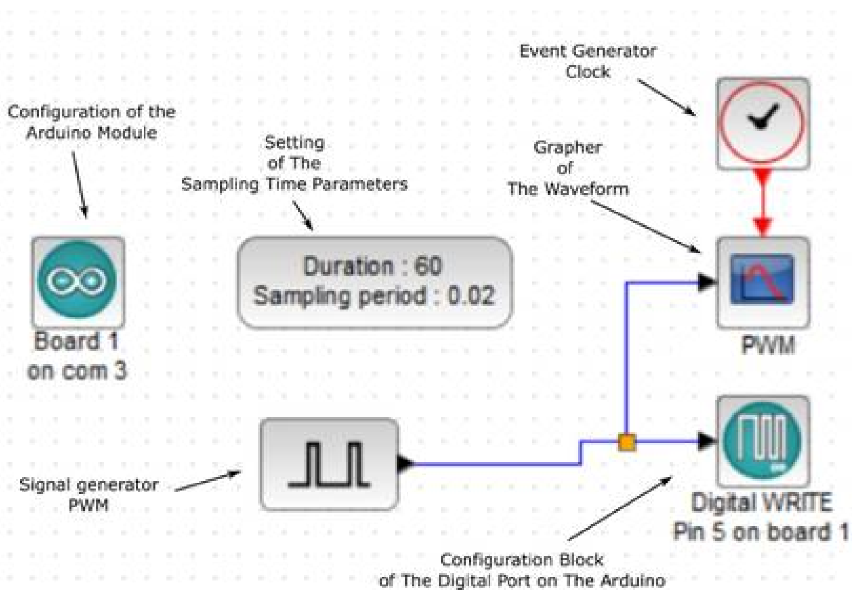

Figure 2. Xcos block diagram to control the output through terminal five of the ArduinoUno, in PWM mode, to control the 2N3053 transistor. (Source: own self.)

The “Digital WRITE” block allows you to define the output terminal of a digital signal. Figure 3 represents the program algorithm in Xcos using a block diagram. In the initialization - configuration stage, the digital output blocks are configured, the pulse width modulation (PWM) generator is initialized, as well as the Arduino configuration block, shown in figure 2.

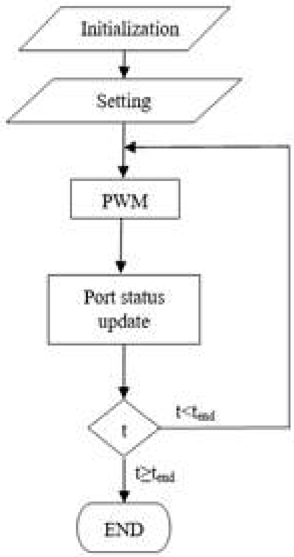

Figure 3.

Algorithm that describes the main operations of the program in Xcos/Scilab to control the coutput through terminal five of the Arduino Uno, in PWM mode. (Source: own self.)

In Figure 4 can see the laboratory practice mounted on the development breadboard. The temperature thermocouple is type K, being very common in industry and portable measurement equipment. The laboratory power supply is calibrated at a voltage of 12 V and an output current limited to 500 mA.

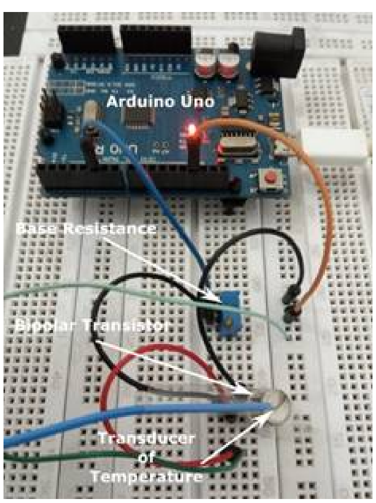

Figure 4. Laboratory practice mounted on a development breadboard. The TO-39 metal-encapsulated 2N3053 transistor, the Arduino. Uno development board, the USB cable,the adjustable potentiometer for resistance R1, theelectrical connections and the temperature probe are observed. (Source: own self.)

To carry out the experiment, it is proposed to use a location that is thermally stable, to obtain an equal starting and ending ambient temperature. Changes in the curve as a result of air currents or changes in the temperature profile of the room are also avoided. In this sense, at the time of carrying out the experiment the stable temperature is 30 °C. A period of 100 ms and a useful cycle of 20% of the PWM signal are set in the Xcos. A stopwatch is recommended to record the temperature values every 5 seconds. The temperature recording must be stopped when the initial temperature with which the experiment begins is obtained again. The time necessary to take the readings was obtained through an empirical process carried out by the teachers. From this laboratory, various analyzes of temperature behavior can be carried out:

- Temperature behavior until the stable state is obtained.
- Transient behavior of heating and cooling of the junction.
- Temperature behavior for transient work regimes of the bipolar transistor.

As an example, the thermal behavior of the semiconductor junction of a transistor will be shown; it will be seen how the temperature varies during heating and cooling of the junction.

As can be seen in the graph in Figure 5, the ambient temperature is 30 °C, and once the transistor is energized, the temperature in the package quickly rises. The approximate maximum temperature is 91 °C, then it decays as a result of the natural cooling of the encapsulation.

One of the most important topics is that the student understands that the heating process is faster than the natural cooling process. It can be seen from the graph that several times the heating time is needed to achieve total cooling. The maximum temperature is reached in approximately 35 seconds, while returning to 30 °C in the encapsulation requires a time of 430 seconds. For the case under study, the cooling time is more than 12 times the heating time.

A small script is then prepared in Scilab to determine the temperature graph at the semiconductor junction. The graph of the junction temperature results is shown in Figure 6.

The maximum junction temperature is approximately 95.9°C, with a difference from the package temperature of 4.9°C. Several protection systems against overheating are based on measuring the temperature in the encapsulation, and from this measurement, the temperature in the semiconductor junction is estimated.

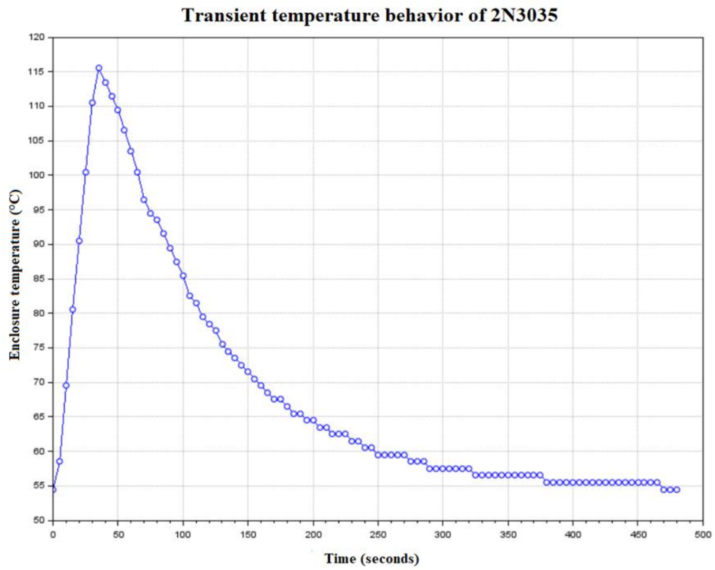

Figure 5. Graph showing the transient thermal behavior of the temperature in the case of the 2N3035 transistor for the heating and cooling regime. (Source: own self.)

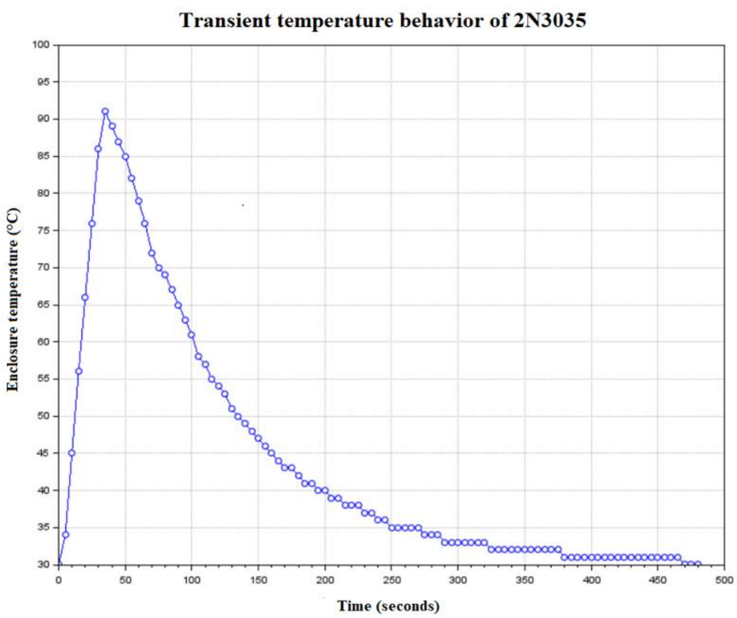

Figure 6. Graph showing the estimated semiconductor junction temperature of the 2N3053 transistor for the heating and cooling regime in a sequence with 20 percent duty cycle. (Source: own self.)

Discussion

With the objective of validating the results after applying the experimental laboratory proposal to determine the thermal behavior of the semiconductors, a structured interview was carried out with the students; 60 students of third-year who took the subjects were taken as a sample for the interviews of Power Electronics and Electrical Circuits in the courses between 2020 -2022 of the Electrical Engineering career, which represent 86% of the year's enrollment.

It is important to note that the method used in carrying out the laboratory practice was problem-based learning, since it corresponds to a real problem of the profession adapted to the contents of the Power Electronics and Electrical Circuits subjects and in line with the professional model proposed in the "E" study plan. In addition, the student is provided with teaching materials and scientific articles that serve as tutorials on the use and configuration of the free Scilab software.

With the use of this method, the role of the teacher changes to that of a tutor or counselor who guides the teaching-learning process of the students in the development of laboratory practices.

For the development of the laboratory practice, with the objective of promoting collaborative learning, the students formed related groups. After completing the laboratory, each team must prepare a laboratory report.

In the interview, five fundamental aspects were assessed; the results are summarized in Table 1.

Table 1. Interview results

Aspects	Good (%)	Regular (%)	Wrong (%)
Motivation	92	6	2
Usefulness of study materials	100	-	-
Vinculation theory - practice	95	3	2
Development of professional skills	88	10	2
Development of self-learning and collaborative learning	92	6	2

As can be seen, more than 88% of the students interviewed consider that the proposal was useful for the development of professional skills, the linking of theory with practice and the development of self-learning and collaborative learning.

On the other hand, 92% of the students consider that this new approach motivated them for the degree because they state that: "the classes are now more attractive and they allow themselves to be less distracted, which helps them to be more motivated during the activities.

Additionally, since they are using electronic devices to carry out the activities, they feel that the classes are more modern."

From the analysis of the results of the surveys carried out, after implementing the proposal, it is confirmed that a theory-practice link is achieved, improving the teaching-learning process of electrical engineering students, specifically in the subject of Power Electronics with a problem-based approach, professional skills are also developed in students, as well as autonomous and collaborative learning, which fosters greater motivation for the Electrical Engineering career. Similar results are shown in the works of authors developed in the references [16 - 18].

On the other hand, the laboratory procedure allows the student to participate in an active, collaborative and meaningful way during all stages. Special attention is paid to reviewing the electrical connections made on the breadboard and capturing temperatures between time intervals.

The use of low-cost hardware and free software not only reduces laboratory costs, but also provides a series of adaptable tools for experimental learning. It is reusable and moldable to new teaching situations.

Time-synchronized temperature measurements provide an opportunity for teamwork, as it requires students to collaborate to record the data obtained.

The implementation of a series of skills in students is achieved. Some of these skills are: deductive reasoning skills and systematic inquiry, creating scientific thinking. Characterizing the temperature behavior of the transistor through measurements allows modeling the relationship between the variables through mathematical equations, developing competence in the analysis and modeling of physical systems through functions, graphs and differential equations. Scilab offers students a powerful platform to process and visualize data, perform complex calculations and model equations.

The fundamental importance of the temperature graph obtained is that it summarizes the temperature behavior in the heating and cooling stages of the electronic component packages, such as transistors. The shorter heating time can be observed, compared to the cooling time, due to the effects of thermal inertia, relevant for design issues of semiconductor cooling systems, as well as for modeling temperature behavior. Although this is explained during classes, experimental verification helps to reaffirm the knowledge taught and motivate students' critical thinking.

Conclusions

An experimental teaching tool was developed to motivate students. It also contributes to the active learning of students and their collaborative participation in laboratory work teams.

Laboratory costs are kept low, since, thanks to free software and low-cost hardware, an instructional and adaptive solution is obtained, suitable for the university environment, without resorting to large licenses or specialized software.

We participate in the use, dissemination and recognition of the potential of free software and low-cost platforms in engineering areas. It helps to break down negative criteria regarding this type of technologies in the university and professional spheres.

Consequently, for the current university to meet today's training demands, the importance of teachers adopting new approaches in the teaching-learning process and in professional training is reiterated, especially in relation to learning. based on problems due to the importance it has in the training of the future electrical engineer, which reflects the nature of engineering itself, given that it is under this scenario in which the future engineer can acquire the knowledge and methods of a scientific nature that will enable him and that can guarantee professional success.

It remains for future work to make improvements to the proposed laboratory, as a possible approach to carrying out laboratories by remote means. The automation of measurements is interesting, as well as the use of Moodle platforms, as an integration of teaching media.

Anexes

The form that served as a guide for conducting the interview was structured as follows:

Question No. 1. In your opinion, do you think that the proposed laboratory activity motivated you for the career?

The responses to this question are shown in Table 2.

Table 2. Results of Question No. 1.

	Frequency	Percent (%)
Yes (Good)	55	92
No (Wrong)	1	2
To some extent (Regular)	4	6
Total	60	100

Question No. 2. In your opinion, do you think that the teaching materials proposed to guide the initiative were useful to you?

The responses to this question are shown in Table 3.

Table 3. Results of Question No. 2.

	Frequency	Percent (%)
Yes (Good)	60	100
No (Wrong)	0	0
To some extent (Regular)	0	0
Total	60	100

Question No. 3. In your opinion, do you think that the proposed laboratory activities helped reinforce the theoretical-practical content?

The responses to this question are shown in Table 4.

Table 4. Results of Question No. 3.

	Frequency	Percent (%)
Yes (Good)	57	95
No (Wrong)	2	3
To some extent (Regular)	1	2
Total	60	100

Question No. 4. In your opinion, do you think that the proposed laboratory activity helped you develop professional skills?

The responses to this question are shown in Table 5.

Table 5. Results of Question No. 4.

	Frequency	Percent (%)
Yes (Good)	53	88
No (Wrong)	6	10
To some extent (Regular)	1	2
Total	60	100

Question No. 5. In your opinion, did participating in the laboratory activity help you exchange knowledge and skills with your peers, as well as contribute to your self-learning? The responses to this question are shown in Table 6.

Table 6. Results of Question No. 5.

	Frequency	Percent (%)
Yes (Good)	55	92
No (Wrong)	4	6
To some extent (Regular)	1	2
Total	60	100

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Authorship contribution

The [three] co-authors participated equally in the stages of research design, data collection, processing, analysis, and writing of the text.

Conflict of interests

The authors declare that does not exist an interest conflict. All authors of the article declare that we fully agree with what is written in this report and approve the final version.

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