Universidad de Vigo

Revista de Investigación en Educación, 2024, 22(1), 87-106
DOI: https://doi.org/10.35869/reined.v22i1.5184
https://revistas.webs.uvigo.es/index.php/reined
ISSN 1697-5200 | e-ISSN 2172-3427

Virtual laboratories for distance learning in STEAM degrees

Laboratorios virtuales para el aprendizaje a distancia en grados STEAM

Miriam Timiraos[1], Francisco Zayas-Gato[2], Álvaro Michelena[3], Elena Arce[4]

[1] Universidade de A Coruña *miriam.timiraos.diaz@udc.es*
[2] Universidade de A Coruña *f.zayas.gato@udc.es*
[3] Universidade de A Coruña *alvaro.michelena@udc.es*
[4] Universidade de A Coruña *elena.arce@udc.es*

Recibido: 19/10/2023
Aceptado: 24/1/2024

Dirección de contacto:
Elena Arce
Polytechnic School of Engineering of Ferrol
C/Mendizábal s/n.
15403. Ferrol (A Coruña)

Resumen

Esta experiencia describe el diseño de laboratorios virtuales para la docencia online en el ámbito de la automatización industrial dentro del Máster en Ingeniería Industrial de la Universidade da Coruña. Este proyecto didáctico involucró tanto a estudiantes nacionales como internacionales en la creación de una planta virtual para transporte y clasificación de paquetes en función del peso empleando Factory I/O y Unity Pro-XLS. Esta experiencia se alinea con los Objetivos de Desarrollo Sostenible (ODS) en contextos educativos. Se realizó una evaluación del desempeño de los estudiantes, comparando entre ejercicios prácticos tradicionales y laboratorios virtuales, la cual arrojó resultados muy favorables.

Palabras clave

Aprendizaje Online, Laboratorios Virtuales, Ingeniería, Automática, Plantas Industriales.

Abstract

This experience describes the design of virtual laboratories for online teaching in the field of industrial automation within the Master's program in Industrial Engineering at the University of A Coruña. The project engaged both national and international students in creating a virtual package sorting conveyor based on weight using Factory I/O and Unity Pro-XLS. The initiative aligns with Sustainable Development Goals (SDGs) in educational contexts. A comparative assessment of student performance between traditional practical exercises and virtual labs yielded highly favourable results.

Key Words

Online Learning, Virtual Labs, Students, Engineering, Automation, Industrial Plants

1. INTRODUCTION

Virtual laboratories play a crucial role in the European Higher Education Area (EHEA) by transforming the way knowledge is taught and acquired in higher education. These tools allow enriching the learning experience by providing students with flexible access to experiments and practices, without geographical restrictions or time constraints. This promotes active, personalized and autonomous learning, which aligns perfectly with the pedagogical principles of the EHEA. In addition, virtual laboratories allow educational institutions to optimize resources and costs, while maintaining the quality of education, thus contributing to the efficiency and internationalization of higher education in Europe. The relevance of the internationalization of European universities was already underlined more than a decade ago in the Leuven communiqué signed by the European ministers in attendance (Patrício and Harden, 2010).

In the coming decades, a high growth of students in tertiary education is expected (Calderon, 2018). However, this growth will be uneven. Thus, higher growth rates are expected in Asia, Latin America, or Africa than in Europe or North America (United Nations, 2017a; United Nations, 2017b). This is due to two factors: on the one hand, the population pyramids in Europe and North America and, on the other, the level of socioeconomic development that are expected to experience certain countries or areas (UNESCO, 2018; World Bank, 2000). If these forecasts come true, on-site teaching-learning models will not be able to absorb this demand. Hybrid and 100% online courses are expected to experience very strong growth (UNESCO, 2018). In the international context, at the present time, the figures for virtual education are still very low. Of the total, it is estimated that only 2% of students receive training exclusively online. In Spain, the figure is higher, with approximately 16% of students in distance learning. Moreover, in the Spanish context (Figure 1), it can be observed that certain regions (autonomous communities) absorb higher rates of external students than others. In the specific case of the Community of Galicia, where the University of A Coruña is located, the number of international students is lower than the national average (Figure 1). Undoubtedly, these data suggest that the transformation from face-to-face to online teaching is an opportunity for universities to increase enrolment figures by attracting international students.

Figure 1. Percentage of international students over total in Spain (%). Source: Ministry of Universities. Spanish Government, 2023

Due to it is possible to apply knowledge through the handling of equipment, the laboratory practices represent an important complement to the theoretical classes.

Considering the internationalization of the degrees and the demand of foreign students who want to learn from their country of origin, an alternative solution could be the remote management and control of the laboratory facilities. Although this approach is interesting, it may not be feasible in some cases, since it would require telecommunications infrastructure and customized software applications to access such equipment. In addition, there would be a lack of physical interfaces to the equipment to establish such a connection.

In the STEAM (Science, Technology, Engineering, Art and Mathematics) environment, laboratory practices, understood as activities for the application of knowledge to concrete situations and the acquisition of basic and procedural skills related to the subject matter, represent an important complement to the expository sessions, by being able to apply this knowledge through the use of equipment and the performance of experiments (De Jong et al., 2013). The literature has shown that inquiry-based science learning, in which students carry out investigations, compared to classical teaching that exclusively includes lectures or demonstrations by the teacher, has innumerable advantages (Singer et al., 2006). Laboratory practices offer students the opportunity to interact directly with materials and/or equipment using tools, data collection techniques, models and scientific theories (European Commission, 2007). Considering the impossibility to perform the laboratory practices in a face-to-face manner in online teaching, an alternative solution is the remote management and control of laboratory plants. Although this approach is interesting, it may not be feasible in some cases, as it requires telecommunications infrastructure and customized software applications to access such equipment. In addition, there is a lack of physical interfaces of the equipment to establish such a connection. Therefore, emulation and virtualization tools emerge as an interesting alternative to address this problem.

In this context, a redesign of the teaching methodology is necessary, integrating the latest advances in Information Technology (IT). Thanks to digitization, nowadays, the combination of software applications for the implementation of virtual laboratories is possible (Vasiliadou, 2020). In this work, the integration of two applications: Factory I/O and Unity Pro-XLS, is used for the construction of a virtual scenario with the objective of emulating industrial plants, serving as a teaching tool for international students. Factory I/O is used for programming and Unity Pro-XLS for visualization.

2. METHOD

2.1. Industrial Automation course

This experience is part of the subject “Industrial Automation” of the Master’s Degree in Industrial Engineering taught at the Polytechnic School of Engineering of Ferrol. The Master's Degree in Industrial Engineering has a total load of 120 ECTS. This master's degree qualifies students to exercise the regulated profession of Industrial Engineer (Order CIN/311/2009). The syllabus of the Master's Degree in Industrial Engineering consists of two academic years and is divided into modules, following the structure established by Order CIN/311/2009 (Spanish framework of professional attributions).

The subject of Industrial Automation belongs to Module 1 (Industrial Technologies), is mandatory and has a total load of 4.5 ECTS. This subject is taught in the first fourmonth period of the first year. The students have different profiles, depending on the undergraduate studies previously taken. The recommended access profile is considered to be the undergraduate degrees in industrial engineering that comply with the Ministerial Order CIN/351/2009. Therefore, the approach of the subject, as well as the selection of resources and materials must be adapted to a wide range of profiles.

The training activities of this subject were divided into lectures, problem seminars and laboratory practices. The evaluation system consisted of a tutored work (90% of the final grade) and a final exam (remaining 10% of the evaluation). The virtual laboratories were used, in the present course, as a methodology for the development of a supervised project. The evaluation methodologies have remained unchanged in the last four academic years. That is, since the 2018-2019 academic year, which was when the last modification of the master's degree curriculum was carried out. The academic year 2022/2023 was the first year of implementation of virtual laboratories as a practical distance teaching methodology.

2.2. Participants

In order to evaluate the effect of the new methodology of virtual laboratory practices on student performance, the grades obtained in the tutored work were compared in two academic years: academic year 2021-2022 (with traditional face-to-face laboratory practices) and academic year 2022-2023 (using virtual laboratories). The tutored work was carried out in groups of 2-4 students.

The student sample for the 2020-2021 course consisted of 29 students, of which 5 were female (17,24%) and 24 were male (82,76%). A total of 11 projects were developed.

The student sample for the 2022-2023 academic year consisted of 31 students, of which 7 were female (22,58%) and 24 were male (77,42%). A total of 10 projects were developed.

2.3. Traditional laboratory practices

The laboratories of the Polytechnic School of Engineering of Ferrol (EPEF) of the University of A Coruña (UDC), are equipped with several scale models that emulate real industrial plants. Some of the most common processes in industrial automation such as weight control, size control, sorting, number of items, etc., are emulated from these laboratory plants. This framework allows students to receive hands-on training and work on projects through physical interaction with this equipment.

One of the mock-ups available in the lab is an industrial package control station (Figure 2), used to perform system automation experiments. However, having only one station makes it unfeasible to work individually, so it is necessary to set up several groups of students for each laboratory session. This is a handicap. The fact of having to work exclusively in groups limits the time that students can interact with the equipment and, therefore, the development of the skills of the course.

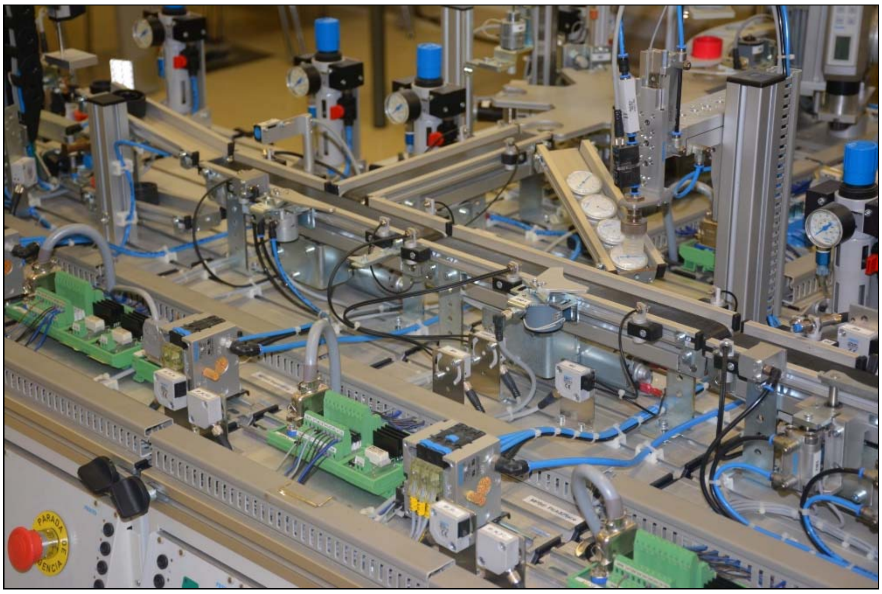

Figure 2. Detail of the industrial package control station

2.4. Virtual laboratory for distance learning

The objective of this practice is to automate a package sorting chain based on its weight. Figure 3 shows the available elements and the requirements for programming the system. As can be seen in Figure 3, the system is mainly composed of 5 conveyor belts: package input conveyor, package weighing conveyor (gage), left output conveyor, front output conveyor and right output conveyor. Each of them is controlled by a motor.

In the central part (before taking the left, front or right path) there is a roller diverter which is controlled by 3 variables: 1) Roller drive, 2) Orientation and deflection of packages to the left, 3) Orientation and deflection of packages to the right.

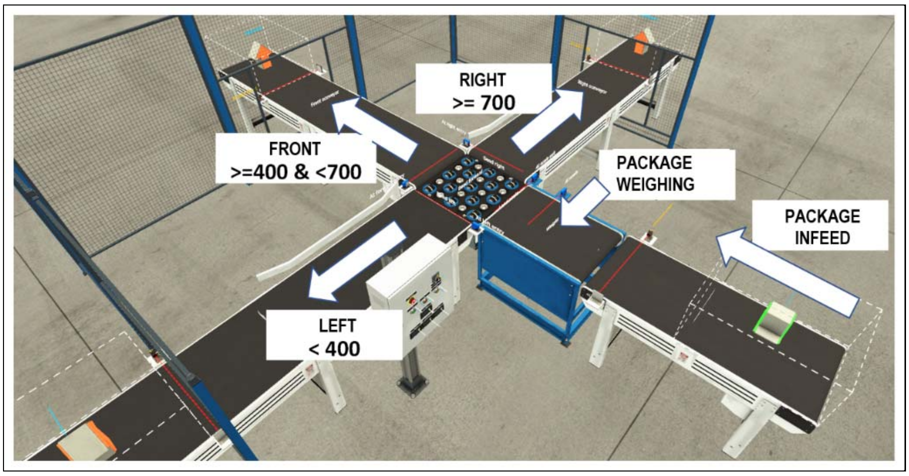

Figure 3. Factory I/O overview of the weight-based package sorting system

If the rollers are actuated and neither the left-hand nor the right-hand deflection is actuated, then the deflection is to the front.

As far as sensors are concerned, the following elements are available:

- Retroreflection photocell on the infeed conveyor, just before entering the package weighing conveyor (scale).
- Diffuse reflection photocell at the position where the package is to be weighed.
- Diffuse reflection photocell on the weighing belt, just before entering the roller diverter.
- 3 Diffuse reflection photocells at the beginning of each exit conveyor (left, front and right).
- 3 retro-reflective photocells at the end of each exit belt (left, front and right).

The photocells are electronic devices that act as photoelectric sensors depending on the light intensity of the environment in which they are located. In self-reflective photocells, the emitter and receiver are located inside the same housing. Thus, the light emitted by the emitter strikes the object to be detected and is reflected, and the receiver is responsible for capturing this reflected light. This type of photocell is widely used in automatic plants due to its low cost. Figures 4 and 5 show the Package classification system details. This graphical information is provided to the students in the practice statement (including images so they can visualize the layout).

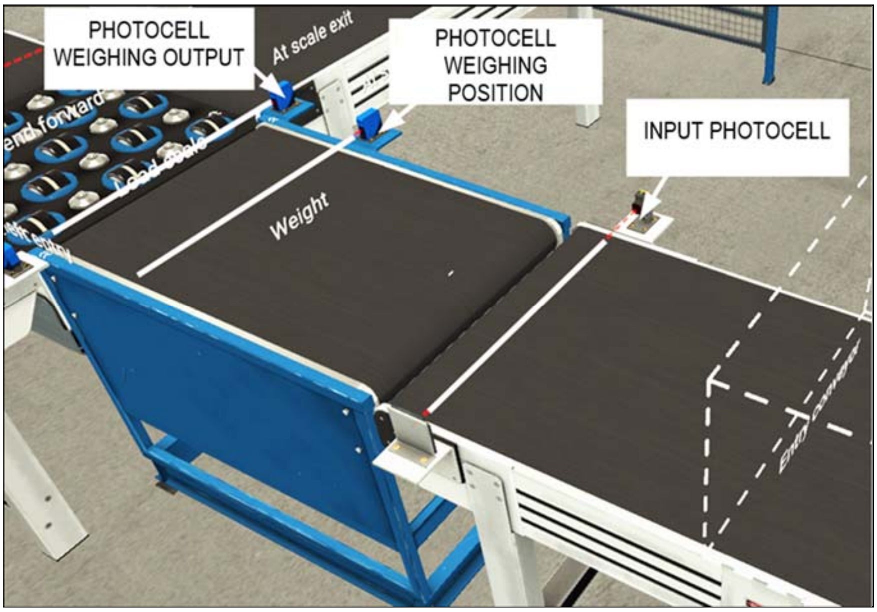

Figure 4. Detail of the conveyor belts and sensors in the layout

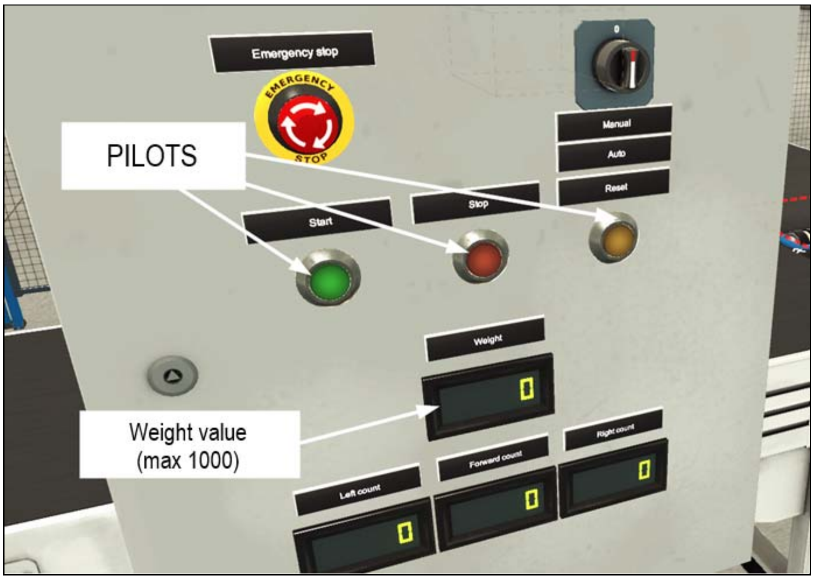

Figure 5. Detail of the layout's control panel

As previously indicated, two software programs were combined for the development of this experience: Factory I/O and Unity Pro-XLS. Factory I/O is a tool for industrial process simulation. Its main objective is to serve as an automation platform with 3D visualization (Riera and Vigário, 2017). This tool incorporates many of the elements present in industrial environments (e.g. motors, pumps, sensors, cylinders or conveyor belts). This allows students to integrate the elements available in the program library and build a customized industrial plant or even a complete virtual factory. Factory I/O serves as a platform for scenes and plants that can be controlled externally. However, it does not include control engineering tools. Therefore, additional components are needed to build a complete control system. This tool includes a wide range of communication protocols (e.g. OPC UA or Modbus TCP), which are widely used in industrial applications. This makes it possible to control virtual plants from third-party software. Unity Pro XLS is a common software for programming, tuning and operation of PLCs (Programmable Logic Control). Unity XLS allows the design of process diagrams (i.e. Grafcet) so that, through a connection to the virtual PLC developed with Factory I/O, it carries out the programmed sequence (Figure 6).

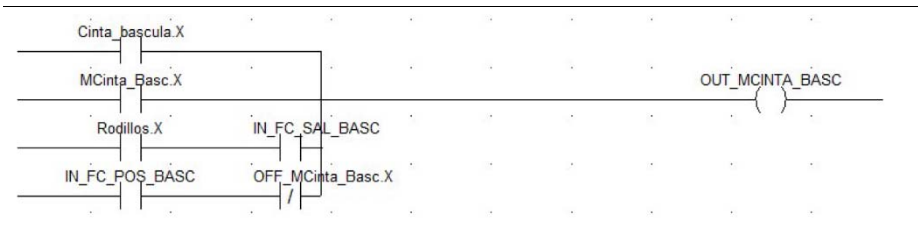

Figure 6. Workflow diagram of one of the tasks submitted by the students

2.5. Instructions given to the students. Proposed scenario

The instructions in an assignment are critically important, as they establish the conceptual and operational framework necessary for learners to understand and execute the task effectively. These guidelines provide clarity on the objectives of the task, the steps to be followed, the evaluation criteria, and any relevant information learners need to successfully carry out the activity. Appropriate instructions foster deep understanding of the topic, promote organization of thought and problem solving, and help students develop critical and analytical skills. They also reduce ambiguity and frustration, which contributes to a more efficient and motivating learning environment. In summary, well-designed instructions are an essential component of maximizing student learning and achievement. In this practice, students are given instructions related to the operation and control and safety of the system.

2.5.1. Operation

The system should operate as follows:

A package enters the sorting system through the package infeed conveyor. This belt must be driven and move the package to the weighing belt. The arrival of the package at the weighing belt can be detected from a photocell. At this moment the weighing belt will be activated. It is recommended to keep the infeed conveyor activated as long as the package continues to interrupt the photocell, to ensure that the package enters the weighing conveyor completely. From there, the weighing belt should move the package towards the scale or weighing point. Arrival at the weighing point is detected by a photocell. At that point, the weighing belt must stop and wait 1 second for the weight value to stabilize. The weight value will be stored with a variable and the following rules must be applied:

- Package weight less than 400: offset to the left.
- Package weight greater than or equal to 400 and less than 700: offset to the front.
- Weight of the package greater than 700: deflection to the right.

Once the weighing is done, the weighing belt will be operated again to bring the package to the diverter. Arrival at the diverter will be detected by a photocell. At this point, the rollers must be actuated and the corresponding outfeed direction must also be actuated. As with the entry of packages, the weighing belt should be kept activated until the corresponding photocell stops detecting the package, to ensure that it enters the roller diverter completely. Subsequently, as soon as the package interrupts the incoming photocell at the corresponding outfeed conveyor, the outfeed conveyor should be activated. After the package stops interrupting the photocell, the roller diverter can be deactivated. Finally, the package is moved to the end of the corresponding exit conveyor until it is detected by the photocell. From this moment on, the outfeed conveyor stops and the cycle would start again with the entry of a new package into the system.

2.5.2. Control and safety

The system starts from a stopped state. In this state, the start-up request must be signaled by the flashing and actuation of the Start pilot light. There are two options: manual mode and automatic mode.

The system will stop at the end of the cycle. In other words, if the Stop button is pressed at any time during the cycle, the system will not stop until the package is taken to the end of the corresponding path.

The system also has a reset option, which returns the system to the initial state.

By regulation, the system also has an emergency stop button for instantaneous shutdown of the entire system. When the button is actuated, the operating and control sections must be forcibly deactivated. When resetting the button, the initialization of the operating section must be forced, ensuring that no packages are left in the middle of the system.

2.5.3. Variables used for simulation development

To reproduce this experience, it is necessary to know the variables used (Tables 1 and 2).

Variable	Description
IN_START	START button
IN_STOP	STOP button
IN_RESET	RESET button
IN_SETA	Emergency button
IN_AUTO	Auto/Man Selector 1: Automatic; 0: Manual
IN_FC_ENT_BASC	Weighing belt pre-entry photocell
IN_FC_POS_BASC	Weighing position photocell
IN_FC_SAL_BASC	Weighing position photocell (weighing belt input photocell)
IN_FC_ENT_FRONT	Photocell front exit conveyor entry photocell
IN_FC_ENT_IZQU	Photocell left exit conveyor entry photocell
IN_FC_ENT_DRCH	Photocell right exit conveyor entry photocell
IN_FC_SAL_FRONT	Front exit conveyor output photocell
IN_FC_SAL_IZQU	Left exit conveyor output photocell
IN_FC_SAL_DRCH	Front exit conveyor output photocell
IN_PESO	Weighing value

Table 1. Input variables

Variable	Description
OUT_MCINTA_ENT	Input belt motor
OUT_MCINTA_BASC	Weighing belt motor
OUT_RODILLOS	Roller drive motor
OUT_DESV_IZQU	Roller diverter rotation counterclockwise
OUT_DESV_DRCH	Roller deflector right hand turn
OUT_MCINTA_FRONT	Front exit conveyor motor
OUT_MCINTA_IZQU	Left exit conveyor motor
OUT_MCINTA_DRCH	Right exit conveyor motor
OUT_PILOT_START	START signal lamp
OUT_PILOT_STOP	STOP signaling lamp
OUT_PILOT_RESET	RESET signal lamp

Table 2. Output variables

2.6. Stages

A detailed overview of the stages involved in the design and implementation of virtual laboratories for international students in a distance learning mode is provided. These stages encompass the entirety of the practical experience, from initial ideation to the final assessment of student performance. The ultimate goal is to shed light on the effectiveness of this innovative approach and its alignment with SDGs in educational contexts, drawing insights from a comparative assessment of student performance in both traditional practical exercises and virtual labs. This didactic proposal is structured in five stages:

- Stage 1: Familiarization with 3D Simulation Software and Analysis of the Virtual Plant.

In this initial stage, students will become acquainted with the 3D simulation software used to create virtual industrial plants. They will be provided with a specific virtual plant and guided to understand the elements that constitute this plant, such as machinery, sensors, actuators, and processes. Students will analyze how these elements interact within the virtual environment and their impact on the overall plant.

- Stage 2: Integration of Control Software and Interconnection.

In the second stage, students will learn to integrate control software into the virtual plant. This involves configuring a programmable logic controller (PLC) within the software and interconnecting it with the virtual plant. Students will gain skills in programming control logic, establishing communication, and configuring digital and analog inputs and outputs to control the virtual plant.

- Stage 3: Development of Proposed Exercises.

The third stage is the core of the activity, where students apply their acquired knowledge. They will be presented with 5 specific exercises related to the control and automation of the virtual plant. Students will design and develop solutions for each exercise using control software and the virtual plant. These exercises may address issues such as process control, production optimization, and fault detection.

- Stage 4: Testing and Debugging

After developing their solutions in the previous stage, students will conduct comprehensive testing on the virtual plant to verify the correct operation of their control programs. During this stage, they will identify and rectify any potential errors and operational issues.

- Stage 5: Submission of the Report and Defense

In the final stage, students will prepare a technical report documenting the entire process, from becoming familiar with the software to exercise development and conducted tests. Additionally, they will present their solutions and results in an oral defense before an academic panel. This stage assesses students' ability to communicate their knowledge and demonstrate the effectiveness of their solutions.

These stages of the industrial automation activity provide students with a comprehensive experience that spans from understanding the basics to practical implementation and result presentation. This prepares them to tackle future challenges in the field of industrial automation and equips them with the skills necessary to design and control complex industrial systems.

2.7. Educational goals

The educational goals of this educational proposal can be categorized into two distinct categories: those pertaining to hard skills and those associated with soft skills. Unlike soft skills, hard skills are discernible and quantifiable in nature:

- Acquire proficiency with the experimental plant.
- Discern and appraise various methods for plant control.
- Familiarize oneself with diverse software tools.
- Demonstrate adeptness in autonomous learning.
- Engage in collaborative and effective communication with peers for project development.

One of the main aims of this experience is to align competencies and methodology. Furthermore, this endeavor aims to amalgamate individual and collaborative efforts. Consequently, the domains outlined in the Malaysian Soft Skills Scale (My3S), which encapsulates the 36 pivotal soft skills delineated by the SkillsMatch project, were employed in the conceptualization of this endeavor. These soft skills encompass seven crucial facets integral to employability: communication, critical thinking and problem-solving, teamwork, moral and professional ethics, leadership, continuous learning, and entrepreneurship (Succi and Canovi, 2020). The soft skills that are developed at each stage of this practice are shown in Figure 7.

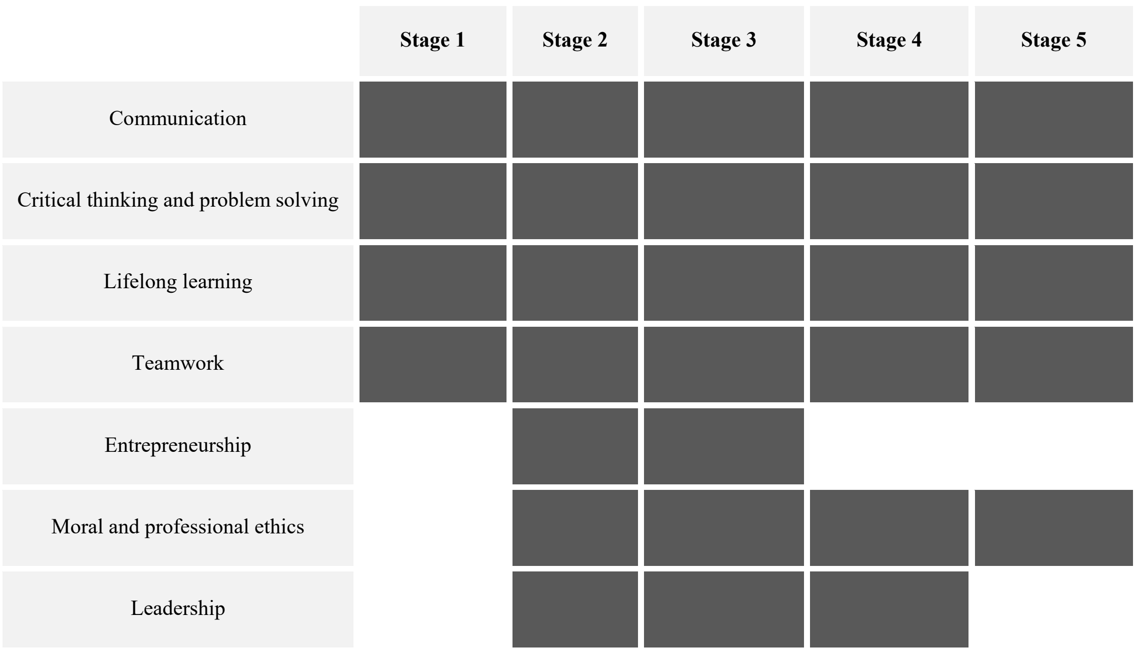

Figure 7. Soft skills developed

There are soft skills that are not developed at all stages. Each stage has a series of characteristics that make them different. All stages are done in teams, so this skill is necessary in all of them. Leadership is something that is developed when students must agree and make decisions, so this skill is not developed in stage 1 or 5. Stages 2 and 3, being initial and key in the development and success of the project, involve the implementation of more competencies. Stage 54, although developed as a team, consists of the presentation of the project and its evaluation, so the entrepreneurial ability is not developed either, as in stages 4 or 1.

This experience focused on five of the 17 SDGs (Figure 8). Each goal is divided into a series of targets (United Nations, 2021). This activity contributes to the development of eight goals: 4.4, 7.1, 7.b, 9.5, 9.b, 12.1, 12.8 and 13.3. The virtual laboratory developed seeks, by applying remote control tools, for students to work on consumption management in a real industrial plant. Virtual laboratories, as opposed to traditional face-to-face laboratory practices, greatly reduce the economic barrier that often limits or prevents interaction with equipment and the development of practices. This contributes to increasing the number of students who develop technical and professional skills for STEAM jobs (target 4.4). Removal of the economic barrier cannot always be guaranteed. The virtual laboratory presented requires the use of computers and the purchase of licenses, which, although they have a small cost, is not zero. If we want to ensure access to affordable, reliable and modern energy services, we must provide STEM students with tools that allow them to learn how to optimize equipment and resources. Virtual laboratories, such as the one designed, allow them to improve the technology that helps provide energy services, which contributes to the development of goals 7.1 and 7.b. The literature has shown that inquiry-based science learning, in which students conduct investigations, compared to teaching focused exclusively on lectures by the teacher, has innumerable advantages (De Jong et al., 2013). The virtual laboratory model developed makes it possible to enhance scientific research, improving the technological capabilities of students and, due to its virtual nature, it is easily exportable to developing countries (goals 9.5 and 9.b). If we introduce control systems to any equipment, responsible production and consumption is made possible, as I can regulate and optimize its operation (goals 12.1 and 12.8). The implementation of control and communication systems to regulate tanks with fluid helps students to identify ways to save water, improving education on climate change mitigation (target 13.3).

Figure 8. SDGs addressed in this didactic proposal

This methodology sought the integration of different teaching approaches (e.g. behaviorist and algorithmic), with the teacher assuming the role of facilitator of the teaching-learning process, instead of working the contents in watertight boxes. This implies that the teacher must be flexible and capable of integrating information from different areas of knowledge. This didactic proposal, a priori, may seem like an overload in the curriculum. However, if we consider the synergies existing between the competences sought and the competences included in the degree report, teaching on sustainability issues does not increase the curricular overload. This experience emphasizes decision-making, critical, and creative thinking, problem solving, analysis, cooperative learning and communication skills.

2.8. Supervised work

The evaluation system for the subject involving this new methodology is based on the completion of a tutored work. The work comprised the automation of a virtual plant with similar components to the real plants at the Polytechnic School of Engineering in Ferrol. The instructions for carrying out the work with the virtual plant (course 2022-2023) were homologous to those developed with physical laboratory plants (previous academic years). The work has a weight of 90% in the overall evaluation. Professors of the subject have been the same during the academic years analyzed. Table 3 shows the specifications for the completion of the project.

Item	Description
1	Download, read and watch the available documentation: - General description of the tutored work. - Video demonstration of the virtual plant operation. - Template for PLC's Integrated Development Environment Unity Pro-XLS. - Virtual plant file for loading the scene into the 3D simulation software Factory I/O. - Unity Pro-XLS and Factory I/O installation files.
2	Install the 3D simulation software. Then, copy the virtual plant file to the proper path.
3	Install the PLC's IDE and load the provided template for programming the exercises.
4	Follow the instructions to complete the 5 proposed exercises. The difficulty increases with each new exercise

Table 3. Items for project completion

Regarding project structure by stages, items 1, 2 and 3 correspond to stages 1 and 2. On the other hand, item 4 corresponds to stages 3 and 4. The projects were evaluated through the submission of a report, a file containing the programmed solution, and a public defense (stage 5). Regarding project submission, the files must be named properly and uploaded as a compressed file containing all files.

The public defense of the tutored works was limited to 5 minutes, plus a question-and-answer session of approximately 2 minutes. All members of the group had to participate in the presentation and defense.

The evaluation weights are shown below:

- 40% report file.
- 40% programmed solution.
- 20% public defense.

All members of the group had to participate in the presentation and public defense of the project. The evaluation of the projects was based on the public defense, the project report and the development of the items (Table 3). An analysis of comparison of means for independent samples (Student's t-test) was performed to determine the effects of the type of teaching (virtual vs. face-to-face laboratory) on the academic performance (grades) of the students. In addition, descriptive analyses were performed.

The supervision and development of the tutored work were conducted using Moodle. The students uploaded the different tasks and evidence on the platform, and professors could provide them with continuous feedback in order to conform a formative evaluation. Tutorials and personalized attention were provided mainly through the Microsoft Teams platform.

3. RESULTS

The students have gained an understanding of the operation of an industrial plant through simulation and virtualization tools. The experience offered by the 3D industrial plant virtualization software enhances the workflow by also allowing interaction with the plant in real time. Figure 9 summarizes the operating scheme of the plant that the students had to automate.

On the other hand, working in groups has encouraged the participation of all students in reaching the best solution to each exercise. In some cases, different students within the group have been responsible for the execution of the different exercises proposed.

Regarding the technical part, the combination of several modern software tools allows them to expand their knowledge of industrial automation. In this sense, they not only focus on programming a PLC but also understand the importance of the integration of different technological elements (sensors, actuators, etc.) or the deployment of industrial communications networks, among others.

It should be noted that this approach provides students with flexibility to carry out their work. In this case, the students have been able to work during vacation time without having to use the physical laboratory.

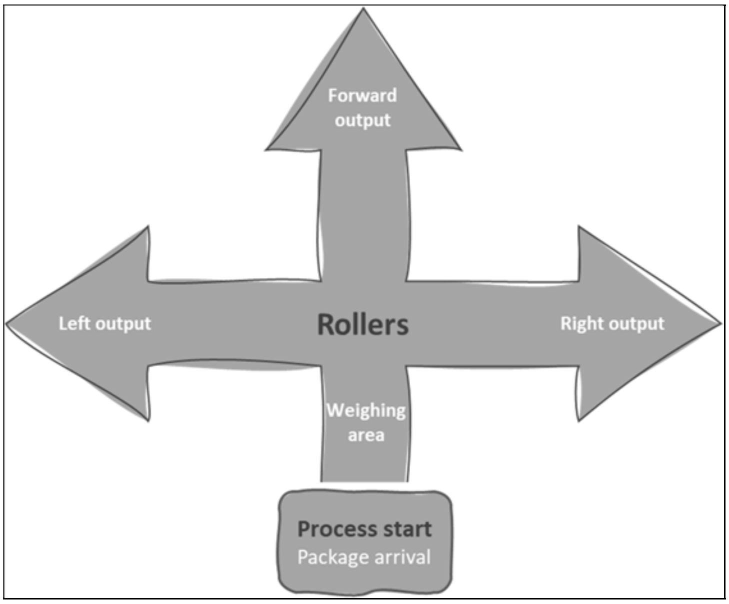

Figure 9. Diagram of the plant operation process

The developed virtual environment can be evaluated and classified based on Potkonjak et al. (2016) four criteria. These criteria are grounded in a key requirement: the students must feel as if they are working with real devices in a real space. Thus, this proposal fulfills three out of the four points, namely: 1) Each user interface is identical to that of real devices; 2) The virtual system's behavior is equivalent to the physical system's behavior; 3) The environment provides a visualization that enables students to feel like they are experiencing a real environment. However, it does not meet the criterion 4 (i.e., the 3D lab space enables communication and collaboration among students and with the lab supervisor or subject expert). Criterion 1 is especially crucial for labs aimed at training system operators. It's worth noting that there may be copyright issues when copying aspects of the real device, and therefore, obtaining permissions may be necessary (Potkonjak et al., 2010). It's important to highlight that out of the 20 virtual lab projects analyzed in Potkonjak et al. (2016) study, only seven met three of the four criteria, and only one met all four, while the remaining proposals fulfilled two or fewer criteria.

The students' performance, in terms of grades achieved, was examined. The results of the effects of the teaching format factor (Virtual Laboratory vs. In-Person Laboratory) on the supervised project assessment revealed that students in the in-person laboratories ($M = 7{,}71$) received a lower grades, $t(57{,}74) = 2{,}34$, $p < {,}05$, $d = 0{,}61$ (moderate effect size), compared to those who conducted the practical exercises in a virtual format ($M = 8{,}42$). Table 4 summarizes the grades obtained.

				Range	
	M[95% IC]	Median	Standard deviation	Min	Max
In-person Lab. (2021-22)	7,51[7,09, 7,92]	7,80	1,18	5,50	9,80
Virtual Lab. (2022-23)	8,18[7,75, 8,61]	8,75	1,18	6,50	10,00

Table 4. Student grades according to type of instruction

3.1. Supervised work

In this experience, we emphasize the importance of clearly defining the learning outcomes associated with the implementation of virtual laboratories tailored for international students engaged in distance learning. The learning outcomes are pivotal as they serve as the foundation for assessing the effectiveness of our approach and ensuring that our students gain valuable knowledge and skills. The learning outcomes may be categorized t into two distinct levels:

a) High-Complex Level Learning Outcomes: At this level, our primary focus is to cultivate a heightened awareness among our students, motivating them to fulfill their academic responsibilities effectively. The design of our virtual laboratory practice allows for close monitoring of student participation, enabling the collection of accurate data regarding their engagement in the proposed activities. To achieve this, we assign specific and individual tasks to each student, and we leverage online tools to ensure that they complete their responsibilities. This level of learning outcomes seeks to foster a sense of individual accountability and active participation.
b) Medium-Defined Level Learning Outcomes: Building upon the high-level objectives, the medium-defined learning outcomes encompass a broader range of competences and skills that students can acquire through this virtual laboratory

experience. By employing the didactic strategies we have outlined and making use of the available resources, students have the opportunity to develop a diverse set of skills and competences. These include:

- Translating Theoretical Knowledge into Practice: Students gain the ability to apply theoretical knowledge to practical scenarios, bridging the gap between classroom learning and real-world application.
- Adaptation to New Responsibilities: The virtual laboratory experience equips students with the skills required to adapt to new roles and responsibilities, fostering adaptability in dynamic work environments.
- Decision-Making Skills: Through practical engagement and problem-solving, students enhance their decision-making abilities, a vital skill in industrial engineering.
- Teamwork: Collaborative tasks within the virtual laboratory promote teamwork, improving interpersonal and group coordination skills.
- Initiative and Entrepreneurship: Students are encouraged to take the initiative, fostering an entrepreneurial spirit and innovative thinking.
- Interest in Quality: The virtual laboratory emphasizes the importance of quality in industrial automation, instilling an appreciation for high standards.
- Troubleshooting: Through hands-on experiences, students develop troubleshooting skills, an essential aspect of industrial engineering.
- Incorporation of Innovative Technologies: The practice encourages students to integrate innovative technologies, contributing to sustainable development and technological advancement.
- Autonomous Work: Finally, the virtual laboratory experience cultivates autonomy, enabling students to work independently and take ownership of their learning journey.

These learning outcomes are strategically incorporated into the five stages of the virtual laboratory design, ultimately contributing to the holistic development of international students in the field of industrial automation:

- Stage 1: Familiarization with 3D Simulation Software and Analysis of the Virtual Plant:
  - By the end of this stage, students will have gained a foundational understanding of 3D simulation software and its role in creating virtual industrial plants.
  - Students will be able to identify and analyze the components within a virtual plant, including machinery, sensors, actuators, and processes.
  - They will develop the ability to assess the interactions between these elements and their implications for the overall plant's functioning.
- Stage 2: Integration of Control Software and Interconnection:
  - At the completion of this stage, students will have acquired the competence to integrate control software into the virtual plant.
  - Students will be proficient in configuring a programmable logic controller (PLC) within the software and establishing interconnections with the virtual plant.
  - They will be capable of programming control logic and configuring inputs and outputs for controlling the virtual plant.
- Stage 3: Development of Proposed Exercises:

  - This stage focuses on the practical application of knowledge, where students will be able to design and develop solutions for 5 specific exercises.
  - Students will exhibit the ability to address issues related to process control, production optimization, and fault detection using control software and the virtual plant.
  - They will demonstrate creativity and problem-solving skills in developing solutions for real-world industrial challenges.
- Stage 4: Testing and Debugging:
  - By the end of this stage, students will possess the skills necessary to conduct comprehensive testing on the virtual plant.
  - They will be adept at identifying and rectifying errors and operational issues in their control programs.
  - This stage hones their ability to ensure the correct and reliable operation of their solutions, emphasizing quality and troubleshooting skills.
- Stage 5: Submission of the Report and Defense:
  - In the final stage, students will demonstrate their capacity to effectively communicate their knowledge and project outcomes.
  - They will produce a technical report that documents the entire process, showcasing their proficiency in technical writing.
  - Through the oral defense, students will present their solutions and results before an academic panel, showcasing their ability to articulate and defend their work, emphasizing presentation, and communication skills. This stage assesses their capability to convey the effectiveness of their solutions and knowledge gained throughout the virtual laboratory experience.

3.2. Lessons learned

From the experience acquired with the design and development of this practice, some lessons learned can be summarized:

- First, the technical resources of the university are a key factor to develop and promote distance learning methodologies. The University of A Coruña through Microsoft Teams offers a means of connection between teacher and student. This platform and the virtual campus (Moodle) facilitate monitoring and control of activities.
- Secondly, the practice of developing automatisms virtually is related to the Sustainable Development Goals (SDGs).
- Thirdly, due to the fact that it has a long learning curve, the handling of specific software for the development of automation practices (i.e. a virtual plant for the classification of elements according to weight) is complex. That is, the student must spend time on autonomous work to learn how to handle such software. While in physical laboratory practices no such effort is required from the student. This should be taken into account by the faculty member in the task design.
- Fourthly, the possible reluctance of faculty to apply new teaching methods and to transform their teaching practices may be the main obstacle to promoting distance teaching in universities that have traditionally taught face-to-face. Therefore, university incentive policies are key to the success of teaching (e.g. Spanish Docentia Program, calls for teaching research projects, etc.).

- Fifth, language barriers. Most resources are in English. Students and faculty with a limited command of English find it difficult to understand the contents of the different programs used and, consequently, are not willing to use digital media.
- Finally, the importance of the teacher's role in monitoring the assignments. Students can experience a broader contextual appreciation if they are forced to develop individual tasks but are supervised by the teacher and accompanied by the rest of the group members through virtual platforms.

In contrast to conventional teaching methods, this experience focused on a constructivist approach to designing virtual laboratories for international students in distance learning, with key lessons emphasizing student autonomy, problem-based learning, a flexible remote environment, student-defined objectives, and continuous assessment. By granting students control over their learning, involving them in real-world problem-solving, providing geographical flexibility, enabling them to set educational goals, and implementing ongoing assessment, this proposal fostered a robust and engaging learning experience, offering valuable insights for educators aiming to enhance the effectiveness and inclusivity of their virtual learning initiatives.

4. CONCLUSIONS

The best way to meet international student demand will be through online education. On-line education eliminates the geographical and cultural barriers that often limit access for international students (Chan et al., 2021; De Vries and May., 2019). Offering online study programs allows international students to access quality education from anywhere in the world, giving them greater flexibility and convenience to suit their individual needs and circumstances. In addition, it significantly reduces the costs associated with moving and living abroad, making education more accessible and attractive to a more diverse group of students. On-line education also fosters cultural diversity and globalization in the academic environment, enriching the educational experience and preparing students for an increasingly interconnected world (Herga et al., 2019).

Throughout the four stages of the project, students develop the seven areas considered crucial for employability (based on the Malaysia Soft Skills Scale (My3S)). The virtual labs also facilitate linkages between the content and the 17 SDGs, without exacerbating the problem of curriculum overload. This is an incentive for the use of this methodology in other subjects in the area where teaching is face-to-face or hybrid.

International students, who study alongside local students, have had the opportunity to attain the upper-tier objectives, such as elevating their motivation to meet academic responsibilities. The allocation of specific individual tasks, coupled with the utilization of a virtual platform, has effectively ensured the diligent execution of these tasks by each international student. This experience aims to underscore the advantages of virtual laboratory programs in not only promoting individual learning but also fostering collaborative learning processes with alignment to SDGs. In this framework, the pivotal role of academic faculty is underscored in striving to attain these objectives, particularly in the context of implementing education for sustainable development within higher education, for the benefit of our diverse international student body.

Within the scope of this experience, the intermediate-level objectives have been successfully realized, encompassing the practical application of theoretical knowledge. Moreover, students have had the opportunity to enhance their adaptability to new responsibilities, refine their decision-making acumen, foster teamwork, nurture an entrepreneurial mindset, and develop proficient problem-solving skills. Additionally, they have acquired the capability to assimilate innovative technologies in pursuit of sustainable development and have seen an augmentation in their self-employment potential.

It is worth mentioning the good results obtained with this work. Based on this proposal, the academic performance of students has improved. A positive effect has been found in the grades in the assignments in virtual format, with respect to the assignments in face-to-face format. These results are in line with what has been reported in previous studies (Herga et al., 2014).

However, this work is subject to design limitations. First, the group assignment was naturally randomized. Consequently, equivalence between groups is not total. Second, the size of the groups limits the power of the results.

Finally, future work may consider the application of virtual laboratories from other experiments and laboratory facilities. In addition, other subjects may benefit from the application of this approach.

ACKNOWLEDGEMENTS

Míriam Timiraos's research was supported by the ``Xunta de Galicia" (Regional Government of Galicia) through grants to industrial PhD (http://gain.xunta.gal/), under the ``Doutoramento Industrial 2022" grant with reference: 04_IN606D_2022_2692965.

Álvaro Michelena’s research was supported by the Spanish Ministry of Universities (https://www.universidades.gob.es/), under the ``Formación de Profesorado Universitario" grant with reference: FPU21/00932.

Elena Arce is a research member of the UNESCO chair Transformative Education: Science, Communication and Society

REFERENCES

Balamuralithara, B. and Woods, P.C. (2009). Virtual laboratories in engineering education: The simulation lab and remote lab. *Computer Applications in Engineering Education*, *17*(1), 108-118.

Calderon, A. (2018). *Massification of higher education revisited*. RMIT University.

Chan, P., Van Gerven, T., Dubois, J.L. and Bernaerts, K. (2021). Virtual chemical laboratories: A systematic literature review of research, technologies and instructional design. *Computers and Education Open*, *2*, 100053. *https://doi.org/10.1016/j.caeo.2021.100053*

De Jong, T., Linn, M.C. and Zacharia, Z.C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*(6130), 305-308. *https://doi.org/10.1126/science.1230579*

De Vries, L.E. and May, M. (2019). Virtual laboratory simulation in the education of laboratory technicians–motivation and study intensity. *Biochemistry and Molecular Biology Education*, *47*(3), 257-262. *https://doi.org/10.1002/bmb.21221*

Herga, N.R., Grmek, M.I. and Dinevski, D. (2014). Virtual Laboratory as an Element of

Visualization When Teaching Chemical Contents in Science Class. *Turkish Online Journal of Educational Technology-TOJET*, *13*(4), 157-165. *https://eric.ed.gov/?id=EJ1043246*

Ministry of Universities. Spanish Government. (2023). *Internationalization Statistics. Course 2021-22*. Retrieved from: *https://www.universidades.gob.es/wp-content/uploads/2023/07/EI-Principales-resultados_2021.pdf*

Patrício, M. and Harden, R.M. (2010). The Bologna Process–A global vision for the future of medical education. *Medical Teacher*, *32*(4), 305-315. *https://doi.org/10.3109/01421591003656123*

Potkonjak, V., Vukobratović, M., Jovanović, K. and Medenica, M. (2010). Virtual Mechatronic/Robotic laboratory–A step further in distance learning. *Computers & Education*, *55*(2), 465-475. *https://doi.org/10.1016/j.compedu.2010.02.010*

Potkonjak, V., Gardner, M., Callaghan, V., Mattila, P., Guetl, C., Petrović, V.M. and Jovanović, K. (2016). Virtual laboratories for education in science, technology, and engineering: A review. *Computers & Education*, *95*, 309-327. *https://doi.org/10.1016/j.compedu.2016.02.002*

Riera, B. and Vigário, B. (2017). HOME I/O and FACTORY I/O: a virtual house and a virtual plant for control education. *IFAC-PapersOnLine*, *50*(1), 9.144-9.149. *https://doi.org/10.1016/j.ifacol.2017.08.1719*

Singer, S.R., Hilton, M.L. and Schweingruber, H.A. (2006). America's lab report: Investigations in High School Science. In *America's Lab Report: Investigations in High School Science*. *https://doi.org/10.17226/11311*

Succi, C. and Canovi, M. (2020). Soft skills to enhance graduate employability: comparing students and employers' perceptions. *Studies in higher education*, *45*(9), 1.834-1.847. *https://doi.org/10.1080/03075079.2019.1585420*

UNESCO Institute for Statistics (UIS) (2018). *Education stats database*. Retrieved from: *http://uis.unesco.org/*

United Nations, (2017a). *World Population Prospects: The 2017 Revision*. Department of Economic and Social Affairs, Population Division.

United Nations (2017b). *World Population Prospects*. Department of Economic and Social Affairs, Population Division. Retrieved from: *https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html*

United Nations. (2021). *The 17 goals*. Departamento de Asuntos Económicos y Sociales. Desarrollo sostenible. Sustainable development. *https://sdgs.un.org/goals*

World Bank (2000). *Higher Education in Developing Countries: Peril and Promise*. The International Bank for Reconstruction and Development.

Vasiliadou, R. (2020). Virtual laboratories during coronavirus (COVID-19) pandemic. *Biochemistry and Molecular Biology Education*, *48*(5), 482-483. *https://doi.org/10.1002/bmb.21407*