Conectividad
ISSN: 2806-5875
ISSN-L: 2806-5875
revista@ister.edu.ec
Tecnológico Superior Rumiñahui
Ecuador

Ampuño Avilés, Gary Omar

Entornos experimentales para la enseñanza de conceptos básicos de automatización industrial

Conectividad, vol. 6, núm. 2, Esp., 2025, pp. 366-373
Tecnológico Superior Rumiñahui
Sangolquí, Ecuador

DOI: https://doi.org/10.37431/conectividad.v6i2.276

REVISTA CIENTÍFICA
CONECTIVIDAD
Instituto Superior Tecnológico Universitario Rumiñahui

Fecha de recepción: 06 / 08 / 2024
Fecha de aceptación: 18 / 10 / 2024
Fecha de publicación: 16 / 05 / 2025

Artículo Científico

Experimental Environments for the Teaching ofBasic Concepts of Industrial Automation

Entornos experimentales para la enseñanza de conceptos básicos de automatización industrial

Gary Omar Ampuño Avilés[1]

[1]Instituto Superior Tecnológico Lemas, gampuno.ups@gmail.com

Autor para correspondencia: gampuno.ups@gmail.com

Citas
Ampuño Avilés, G. (2025). Entornos experimentales para la enseñanza de conceptos básicos de automatización industrial. CONECTIVIDAD, 6(2). https://doi.org/10.37431/conectividad.v6i2.276

ABSTRACT
This paper addresses the implementation and use of a remote experimental environment in industrial automation education, highlighting the importance of combining theory with applied practices. During the COVID-19 pandemic, the need to access laboratories remotely was highlighted, which has led to the creation of virtual laboratories to allow students to perform practices from their homes. And currently, although laboratories are accessed in person, remote access gives flexibility to students to perform practices independently avoiding crowds due to the number of modules in the laboratory or the opening hours. A case study is presented in which a SCADA system is programmed to control the temperature of a tank. In this study a PID controller is implemented, achieving an error of 2.4%.
The effects of the use of remote laboratories are analyzed in a universe of 162 students. In face-to-face mode, 62 students would have difficulties to access the modules. However, currently, 100% of the students have access to the practices thanks to the implementation of these laboratories. The versatility of the implemented modules is highlighted and the importance of adapting to technologies such as IoT to facilitate access to the laboratories from any location is emphasized, thus promoting more effective and safe learning in the field of industrial automation.

Keywords: Experimental environments; Industrial process modeling; Remote laboratories; Take-home Lab.

RESUMEN
Este artículo aborda la implementación y el uso de un entorno experimental remoto en la formación en automatización industrial, destacando la importancia de combinar la teoría con la práctica. Durante la pandemia de COVID-19, se puso de manifiesto la necesidad de acceder a los laboratorios de forma remota, lo que ha llevado a la creación de laboratorios virtuales que permiten a los estudiantes reali-zar prácticas desde sus hogares. Actualmente, si bien el acceso a los laboratorios es presencial, el acceso remoto brinda flexibilidad a los estudiantes para realizar prácticas de forma independiente, evitando aglomeraciones debido al número de módulos en el laboratorio o al horario de atención. Se presenta un caso práctico en el que se programa un sistema SCADA para controlar la temperatura de un tanque. En este estudio, se implementa un controlador PID, logrando un error del 2,4%. Se analizan los efectos del uso de laboratorios remotos en un universo de 162 estudiantes. En la modalidad presencial, 62 estudiantes tendrían dificultades para acceder a los módulos. Sin embargo, actualmente, el 100% del alumnado tie-ne acceso a las prácticas gracias a la implementación de estos laboratorios. Se destaca la versatilidad de los módulos implementados y se enfatiza la importancia de la adaptación a tecnologías como IoT para facilitar el acceso a los laboratorios desde cualquier ubicación, promoviendo así un aprendizaje más efectivo y seguro en el ámbito de la automatización industrial.

Palabras clave: Ambientes experimentales; Modelado de procesos industriales; Laboratorios remotos; Laboratorio para llevar a casa.

Fecha de recepción: 06 / 08 / 2024
Fecha de aceptación: 18 / 10 / 2024
Fecha de publicación: 16 / 05 / 2025

1. INTRODUCCIÓN

Throughout time, university education has seen as a challenge to bring to the classroom the basic concepts of the operation of industrial systems and their automation. This for students to translate in a tangible way what they have seen in theory with practices that emulate these physical phenomena in the industrial field. Every day more and more students are supported by technologies compacting diverse processes in didactic modules, having as a novelty that they are not acquired, but are designed according to the advance of technologies in this field. During the COVID 19 pandemic, the criterion of laboratories that allow students to develop practices to complement the theory seen in class, but accessing them from the safety of their homes, is further strengthened. Works such as [1], [2] present their results as successful cases giving the complement of experimentation to the students. Different areas of education have been able to be improved as seen in research developments such as [3]-[5] where remote tools are applied to the use of laboratories in fields such as chemistry, programming and even neuromarketing. Specifically in the teaching of industrial automation, complementing the theory seen in the classroom with practices using equipment currently used in the industry benefits students and companies [6]. This is because, when going out to the industrial field, the training and adaptation process are less. Studies such as [7], [8] describe level processes implemented in modules that use sensors and real industrial equipment that allow students to familiarize themselves from the classroom with these technologies and the calibration of sensors, such as calculations for the control loops to have an acceptable error. This avoids that now of the assembly of an industrial plant the tests at the time of the start-up of these, raw material is lost and to avoid the damage of the machineries when not complying with the limits of these.

With the studies indicated above, students must go to the laboratories to access the practices sometimes saturating these spaces. With the advancement of technologies such as IoT for remote access, the paradigm Take-Home Lab [9], [10] is born, which helps students from anywhere in the world to access the laboratories and perform the practices in different schedules.

Thus, the second section of this work is dedicated to briefly describe the modules implemented for teaching industrial automation. Subsequently, a practice that covers all the topics covered in the subject of industrial monitoring and automation is presented to give the reader a global view of the versatility of the module. Section 4 shows some results obtained by the students. Finally, some conclusions of the work will be shown.

2. METHODOLOGY

Since 2020 and considering the challenge of enabling remote laboratories for students who, due to the COVID 19 pandemic, had to study from home. Laboratory practices are the forte of engineering careers and it is essential that students complement theory with application cases. Thus, several universities were prepared with remote laboratories; but, in the study presented below, the Salesian Polytechnic University, having all its classes in person, immediately

Fecha de recepción: 06 / 08 / 2024
Fecha de aceptación: 18 / 10 / 2024
Fecha de publicación: 16 / 05 / 2025

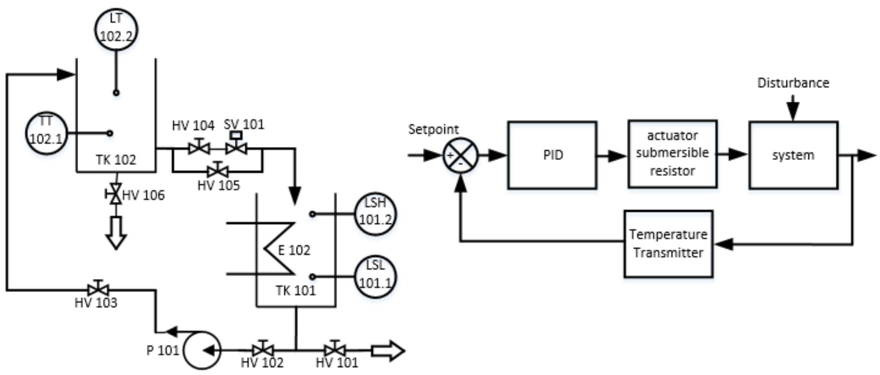
activated several alternatives with technologies for students to access remotely.

Specifically in the industrial automation laboratories, a network of virtual/earthquake laboratories is implemented for teaching automation. By means of an agenda, students could access the laboratories (with IP addresses) respecting shifts. The visualization of the actuators and sensors was done by means of cameras focused on the industrial plants and modules. Figure 1 shows the structure of the laboratory.

The laboratory was implemented at the Universidad Politécnica Salesiana Guayaquil - Ecuador. The laboratory has 20 computers connected to a network consisting of 40 access points; the remaining 20 points will be used to connect industrial automation and substation automation equipment such as Siemens, Allen Bradley and Schneider programmable logic controllers, intelligent relays SEL 751, 387, 421.

Through remote access programs and specific addresses assigned throughout the network; the student with his computer from any location will access the lab computer. The computer is equipped with a camera that points to the equipment that will be used for the practices. To avoid the need for university personnel to come to the labs to turn on the lights, intelligent switches are placed so that when the lights are remotely accessed, they are activated, and the lab is illuminated for the practices.

Figure. 1. Scheme of network connections and distribution of equipment



This paper presents a case study that is part of the practices that are being used in various automatic control courses for teaching and learning basic concepts of modeling and control.

2.1 Case Study

The case study presented below is for teaching industrial automation and is a module that uses the Siemens S7-1200 CPU 214C PLC programmable logic controller. In Figure 2, the module and its external components are presented. The module is complemented with industrial sensors such as proximity (inductive) for the digital inputs, a temperature sensor with its respective transducer for the analog input signals and a DC motor as actuator for the digital outputs.

REVISTA CIENTÍFICA
CONECTIVIDAD
Instituto Superior Tecnológico Universitario Rumiñahui
Fecha de recepción: 06 / 08 / 2024
Fecha de aceptación: 18 / 10 / 2024
Fecha de publicación: 16 / 05 / 2025

Figure. 2. a) PLC module SIEMENS S7-1200 CPU 214C, b) Proximity sensor (digital input), c) Proximity sensor (digital input), and d) DC motor (digital output).

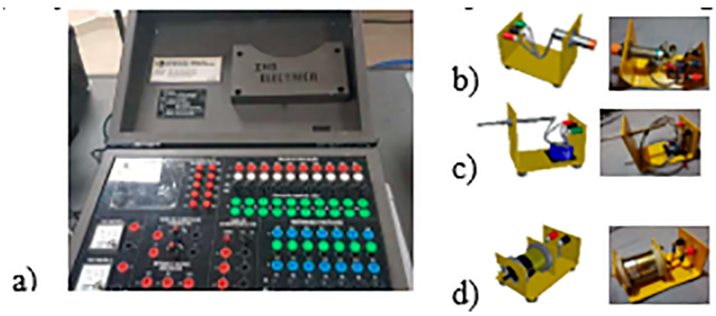
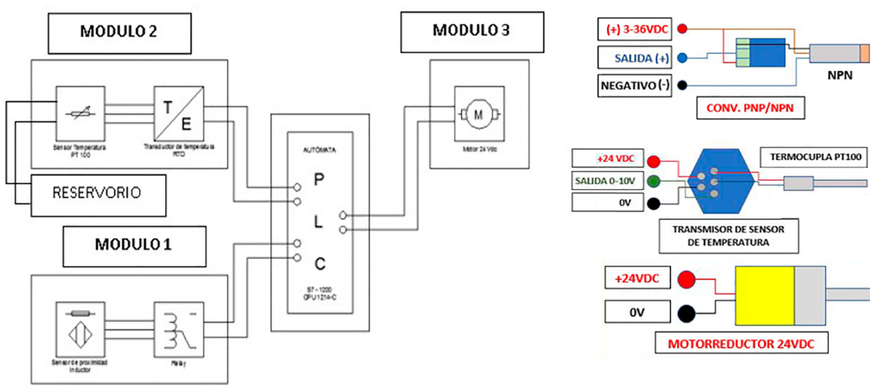


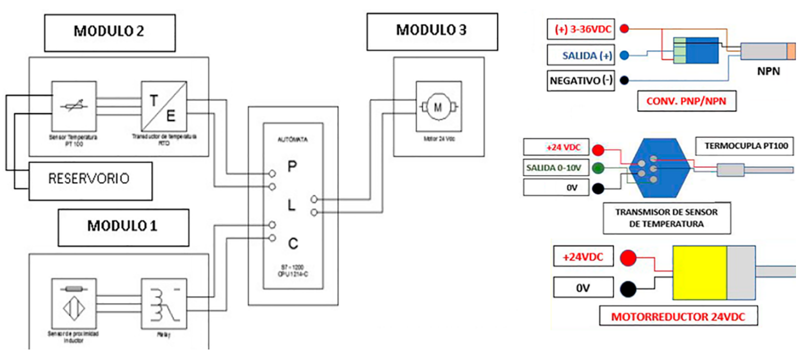
Figure 3 shows the system assembled for the practices. Where the sensors are electrically connected to the main PLC module. In turn, the sensors are physically placed in the industrial plant that has a reservoir for the heating process and a conveyor belt for counting objects.

Figure. 3. Electrical wiring diagram of the PLC module and its external components



With this configuration the control loops available for a basic control course are temperature and object counting. In the temperature control loop the variable to be controlled is the temperature of the process circuit. Figure 4 shows the arrangement of these elements in the heating circuit. The controller, in this case, receives the actual temperature value from the transmitter, processes it and sends it to the submersible resistor (connected to one of the digital outputs of the PLC). On the other hand, you can see the two-way valve that is responsible for introducing the disturbances to the system.

Figure. 4. Temperature control loop and system P&ID diagram



Fecha de recepción: 06 / 08 / 2024
Fecha de aceptación: 18 / 10 / 2024
Fecha de publicación: 16 / 05 / 2025

The temperature circuit model would be given by the following differential equation:

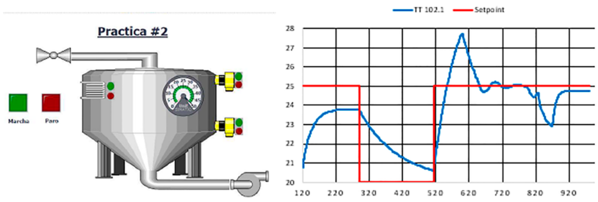
$$m \cdot C_e \cdot \frac{dT_{(t)}}{dt} = k \cdot \gamma_{(t)} \cdot C_e \cdot (T_c - T_{(t)})$$

Where m is the mass of the process liquid. C_e is the specific heat, T es is the process circuit temperature, k is the Flow constant, γ is the valve temperature and T_c is the water temperature in the heating circuit.

2.2 Practice environment

The objective of the development of this laboratory is to combine virtual and remote environments with teaching resources to complement the theory of the subject with the application case practices. The following is one of the practices developed by the students using the environment. Figure 5 shows an example of programming a Supervisory Control and Data Acquisition (SCADA) for temperature process control. In this application, sensors are added to ensure the correct operation of the system and to avoid failures or damage to the system. In the graph that accompanies the SCADA, a history of the behavior of the tank temperature (blue) vs. the setpoint selected for the control (red) can be seen. Throughout the practice, once the level and temperature control loops are implemented, students are instructed to calculate the controller parameters (PID).

Figure. 5. SCADA system for the temperature process



3. RESULTS

3.1 Practice with implementing the temperature system

In this section the results obtained by the students are shown as an example. Specifically, the results of the temperature circuit will be shown.

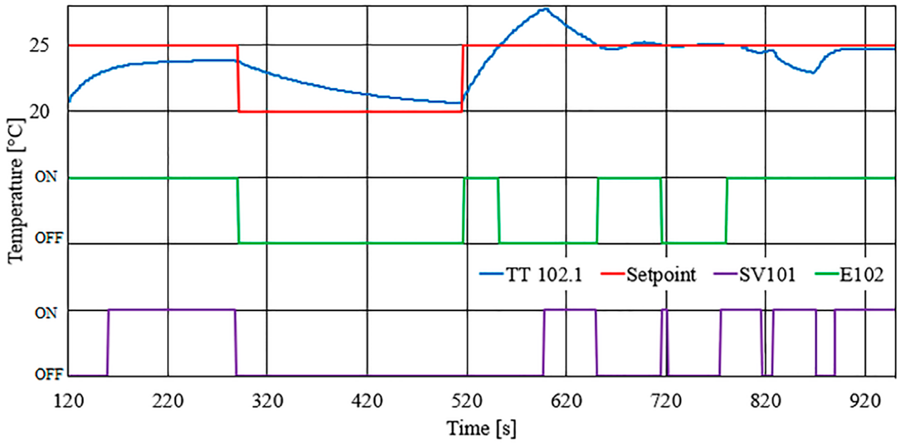
First, students must perform the programming of the PLC and SCADA to be uploaded remotely to the equipment. Once the operation is established, the PID control block that is incorporated in the PLC for temperature control is executed by turning on and off the output connected to the submersible resistor.

Figure 6 shows the behavior of the temperature in tank TT102.1. At the beginning, a setpoint of 25 °C (red line) is set, which is maintained for 180 seconds. During this time, the submersible resistor E102 is turned on, as shown by the green line, which causes the temperature to begin to increase from the ambient temperature at 21 °C and to reach about 24 °C. During the second 150, the cold-water valve SV101 is opened, this action does not allow the temperature to be

REVISTA CIENTÍFICA
CONECTIVIDAD
Instituto Superior Tecnológico Universitario Rumiñahui
Fecha de recepción: 06 / 08 / 2024
Fecha de aceptación: 18 / 10 / 2024
Fecha de publicación: 16 / 05 / 2025

higher inside the tank. Once the 180 seconds are reached, the setpoint is changed to 20 °C and the SV101 valve and the E102 resistor are turned off. This shows the temperature behavior, which drops by about 3.5 °C in 340 seconds. As a final test, the setpoint is increased again to 25 °C and only the E102 resistor is turned on, without the cold-water inlet action the temperature rises above 25 °C. Finally, the SV101 valve is opened to see the PID behavior. The root mean square error of the controller action results in 2.3 °C.

Figure. 6. Temperature system



3.2 Analysis of the effects of the use of the remote laboratory on students

The following are some data corresponding to the students who have taken one of the industrial automation subjects in different academic periods. These data show the benefits of the use of remote laboratories, especially because there are few modules and due to the restriction of physical spaces, some students were not able to develop the practices comfortably. Figure 7 shows the grades obtained in the mastery by the 162 students who have taken the course from 2020 to the present. There are 151 students who pass the course and 11 who fail it. Not necessarily those who fail are due to the non-use of the modules and, on the contrary, not all of those who pass may be able to comfortably perform the practical exercises in the laboratory.

Figure. 7. Universe of students used to analyze remote laboratory use.

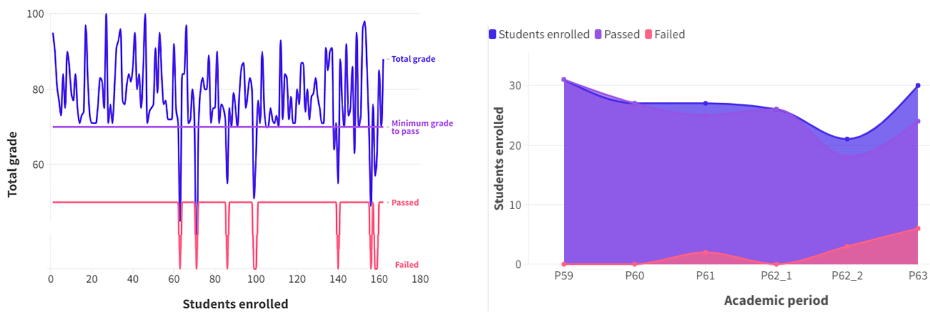


Figure 8 and Table 1 graphically represent the number of students who were left without a module in the laboratory versus the number of students enrolled. The laboratory has a capacity for 24 people, but the number of modules is 10, therefore, the practice must be done in pairs, resulting in 20 students per class. In a face-to-face manner, there are alternatives for students

REVISTA CIENTÍFICA
CONECTIVIDAD
Instituto Superior Tecnológico Universitario Rumiñahui

Fecha de recepción: 06 / 08 / 2024
Fecha de aceptación: 18 / 10 / 2024
Fecha de publicación: 16 / 05 / 2025

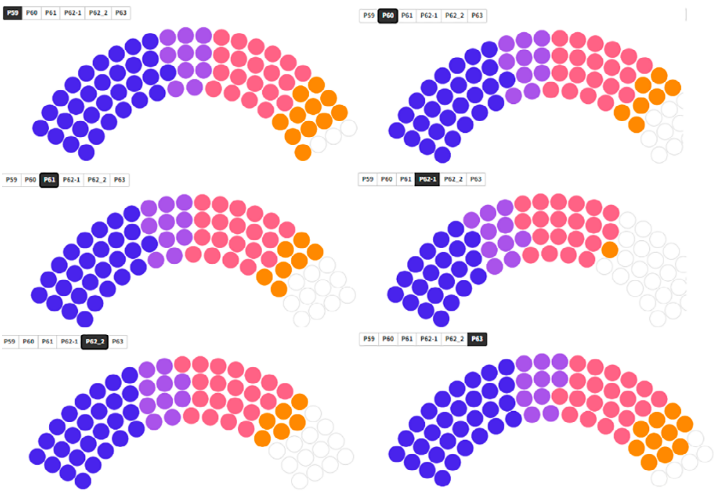
who do not reach modules, such as the use of these in other schedules and weekends; this incurs the use of personnel for the opening of the laboratories and of teachers who also work in other days so that they can supervise the good use of the laboratories.

Table 1. Data on students with access to laboratories.

	P59	P60	P61	P62 1	P62 2	P63
Students Enrolled (blue)	31	27	27	21	26	30
Available modules (purple)	10	10	10	10	10	10
Students whit access to the modules (pink)	20	20	20	20	20	20
Students without access to the modules (orange)	11	7	7	1	6	10

Through the implementation of the remote laboratories, not only students who do not have access to the laboratories in person have access to the laboratories, but also students who shared a module with another classmate can develop the practices independently. This ensures a complement between theory and practice.

Figure. 9. Enrolled students in blue, availability of modules in purple, students who have access to the on-site laboratory in pink and students who do not have access to the modules in orange.



4. CONCLUSIONS

The current work highlights the importance of implementing virtual and remote environments in the teaching of industrial automation. Remote laboratories have proven to be an effective tool to complement theory with applied practices, allowing students to access hands-on experiences in a personalized way and not only in groups where they sometimes felt they needed to practice more. As educational institutions also emphasize the need to adapt to emerging technologies such as IoT to facilitate access to labs and improve the quality of education in this field to prepare students for the challenges of modern industry.

REFERENCES

J. Vargas, J. Cuero, and C. Torres, "Laboratorios Remotos e IOT una oportunidad para la formación en ciencias e ingeniería en tiempos del COVID- 19 : Caso de Estudio en Ingeniería de Control," *Rev. Espac.*, vol. 41, no. 42, pp. 188–198, 2020, doi: 10.48082/

espacios-a20v41n42p16.

D. Herrero-Villareal, C. Arguedas-Matarrita, and E. Gutiérrez-Soto, "Laboratorios remotos : recursos educativos para la experimentación a distancia en tiempos de pandemia desde la percepción de estudiantes Remote laboratories : Educational resources for," *Rev. Enseñanza la Física*, vol. 32, pp. 181–189, 2020.

J. López-Solorzano and C. Ángel-Rueda, "Revisión sistemática de los entornos digitales inmersivos tridimensionales en la enseñanza de la programación," *Rev. Educ. a Distancia,* vol. 23, no. 73, 2023, doi: http://dx.doi.org/10.6018/red.540731.

M. Arroba Arroba and S. Acurio Maldonado, "Laboratorios virtuales en entorno de aprendizaje de química orgánica , para el bachillerato ecuatoriano," *Rev. Científica,* vol. 8, no. 3, pp. 73–93, 2021, doi: https://doi.org/10.35290/rcui.v8n3.2021.456.

L. Cerdá-Sánchez and C. Cristófol-Rodriguez, "An exploratory study on the impact of neuromarketing on virtual learning environments," *Vivat Acad*., vol. 115, pp. 1–16, 2022, doi: http://doi.org/10.15178/va.2022.155.e1391.

D. Muñoz, M. Domínguez, F. Gomez-Estern, Ó. Reinoso, F. Torres, and S. Dormido, "Estado del arte de la educación en automática," *Rev. Iberoamerica Automática e Informática*, vol. 19, pp. 117–131, 2022.

G. Ampuño, W. Agila, and H. Cevallos, "Implementación y analisis de rendimiento de un control industrial de nivel para tanques con fluidos, basado en lógica difusa.," MASKANA, I+D+ingeniería, vol. 5, pp. 27–36, 2015.

Á. Tumbaco, R. Viña, and G. Ampuño, "Segundo Congreso Salesiano de Ciencia, Tecnología e Innovación para la Sociedad," in Segundo congreso salesiano de ciencia, tecnología e innovación para la sociedad, Editorial Universitaria Abya-Yala, Ed. Guayaquil, 2016, pp. 177–183.

A. Hoyo, F. García-Mañas, J. Ramos-Teodoro, J. A. Sánchez-Molina, J. L. Guzmán, and F. Rodriguez, "Uso del paradigma Take-Home Labs para la enseñanza del control automático en estudios de ingeniería," XLII Jornadas Automática, vol. 42, pp. 218–225, 2021, doi: https://doi.org/10.17979/spudc.9788497498043.218 225.

M. Domínguez González et al., "Demostradores para la formación en digitalización de la industria," Premios a la innovación en la enseñanza, León - Mexico, pp. 65–116, 2022.