COVID-19 Impact on the Laboratory Practices of the Automation Subjects at the University of La Laguna

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Abstract: Our practice programs have changed drastically after the appearance of COVID-19. The practical sessions designed for all Automation subjects until 2019 were face-to-face. But the arrival of the pandemic and health restrictions resulted in the closure of our university facilities, which forced us to redo the laboratory experiences. It is in this context that simulation and gamification helped us to move forward, since the solution we followed was the virtualization of the laboratory. Although the degree of satisfaction of the students with the new practical sessions is quite good, the purpose of this paper is not to present a detailed analysis of all the simulation and gamification tools we studied, but to explain what our situation was like before COVID-19, how we faced the change, what we learned in the process, what the new practice programs we are currently following are like, what tools have helped us, and what goals we still have to achieve. We hope that our experience can be useful to other teachers.

1 INTRODUCTION

It is well known that practical sessions in engineering are essential for the acquisition of the discipline's competences. For this reason, all educational plans in university schools include them in their subjects. Automation is no exception; in fact, it is probably one of the fields where laboratory practice is the most enriching for students.

The authors of this work are teachers at the School of Engineering and Technology of the University of La Laguna. Part of their teaching is in the area of Automation. Depending on the course, they teach Automation subjects with different levels of complexity. This requires the design of practice programs differentiated in methodology and learning objectives. Planning automation laboratories is not a trivial task, since usually the schools do not have enough space or budget to incorporate real industrial plants to their practice programs. This is where simulation comes into play, providing important advantages from an educational point of view. There are many studies that demonstrate the benefits of simulation in the field of Education. In particular, the last decade has seen a remarkable increase in the use of simulators in the teaching of automation: PLCSIM (Calderon et al., 2018), Codesys (Kaneps et al., 2016), CIROS (Freund et al. 2000), OpenPLC (Alves et al., 2014), Factory I/O (Vargas et al., 2022), etc. These simulators allow users to model an industrial plant, predict the behavior of a process, simultaneously analyze different cases by modifying variables in real time, optimize operating conditions in existing or new plants, and monitor a plant throughout its useful life. Although many of these simulation tools are not free, the cost of the licenses is much lower than that of any real industrial plant, making it a very interesting alternative, and sometimes the only possible one, when resources are limited.

On the other hand, the use of gamification as a tool to increase students' interest and motivation in subjects has spread to cover all educational levels, from early childhood to higher education. There are numerous works that highlight the multiple advantages of gamification in classroom and distance education, such as (Seaborn et al., 2015; Hamari et al., 2016; Sousa et al., 2022, Manzano et al., 2020, Ycekaya et al., 2021). The idea of learning by playing is very attractive in all fields, but in the field of

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automation it is also relatively easy to carry out with the help of the simulators mentioned above.

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2 PRACTICE PROGRAM PRIOR TO COVID-19

Practical sessions in Automation subjects, until the advent of COVID-19, took place in the laboratory on a face-to-face basis. The following is a brief description of these pre-COVID-19 practice programs.

2.1 Introductory Automation Courses

The automation practices for the introductory automation courses consisted of simulating very basic processes on the Programmable Logic Controllers (PLC) present in the laboratory. These PLCs are Siemens S7-1200. Each PLC had an external board with switches connected to its input interface, to manually activate and deactivate the system inputs, and thus simulate the activation and deactivation of hypothetical sensors connected to the PLC. The students proposed a KOP code of the proposed problem, loaded it into the PLC, and checked its proper functioning by activating and deactivating these switches, simulating the occurrence of events in the system.

The practice program consisted of several sessions where the students tackled the programming of simple problems:

- Session 1: introduction to Tia Portal and to PLC S7-1200.
- Session 2: automation of a garage door.
- Session 3: control of the capacity of a public parking.
- Session 4: automation of a traffic light.
- Session 5: control of a chemical process, a mixer or a precise weighing system.

2.2 Advanced Automation Courses

Advanced automation students tackle the programming of the Festo educational plant available in our laboratory (Festo, 2023). This plant has five stations controlled with Siemens S7-1200 and S7-1500 PLCs. The students, divided in groups, perform the programming of one station and the communication with the remaining stations. Figure 1 shows the five Festo stations:

- Station 1: Storage and distribution of parts.
- Station 2: Parts size measurement and classification.
- Station 3: Parallel processing of parts.
- Station 4: Pneumatic arm for parts manipulation.
- Station 5: Parts sorting and storage.

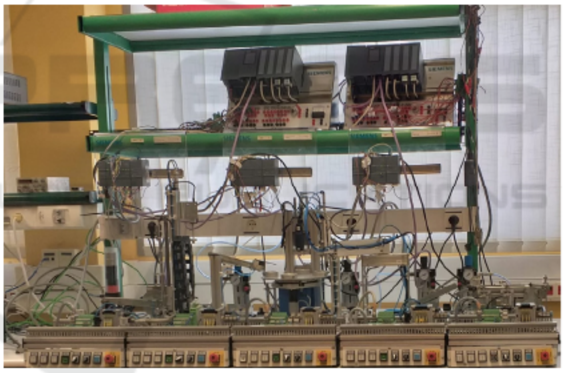

Figure 1: FESTO educational plant.

3 STATUS OF AUTOMATION PRACTICES WITH COVID-19

The arrival of the pandemic and health restrictions led to the closure of our university facilities. The teaching activity was resumed in a non-presential way, through videoconferences and audiovisual material, which each professor carried out as best he could at home with the personal means at his disposal. Evidently, we were not prepared to face such an abrupt change, and this negatively affected the quality of teaching in the first months of the pandemic.

The practical activities of the subjects were the most affected by the lack of face-to-face attendance.

In our case, the most immediate solution was to convert the Automation practices of all the subjects into simulated practices. For this purpose, the Siemens simulator included in the Tia Portal (Tia Portal, 2023), the S7-PLCSIM program, was used. This emergency solution presented several major drawbacks:

1. We were forced to explain the operation of the Tia Portal and the simulator through videos.
2. From a pedagogical point of view, especially for the students who had to simulate the programming of the Festo plant, it was difficult to imagine what the system they had to control looked like without being able to see it physically. They were provided with explanatory videos of the operation of each station, but even so, the task of debugging the code without working with the real plant was not easy.
3. The Tia Portal and its PLCSIM simulator are proprietary programs. Although temporary licenses were purchased for all students, some had problems installing and running the software on their personal PCs, because it is a very computationally demanding program.

These circumstances pushed us to look for new technological solutions that would allow us to teach practical sessions remotely in a more efficient way, and that could also be used in face-to-face sessions, when they were resumed. We clearly saw that there was a need to virtualize the Automation laboratory in order to make teaching more flexible and make the practical sessions more accessible to students, and to do so quickly, since at that time there was great uncertainty about how the health situation would evolve. The use of virtual laboratories for the practical teaching of Automation is not a new idea (Potkonjak et al., 2016), but in our case, we had not had the need to implement it until this moment. Therefore, we started to study and analyze the applicability of different simulation and gamification tools for the virtualization of our laboratory.

4 FINAL SOLUTION ADOPTED: VIRTUALIZATION OF THE AUTOMATION LABORATORY WITH FACTORY I/O

Our efforts were focused on designing a virtual tool for practical laboratory teaching, with the objective of developing new practical teaching in various contexts:

- In the context of confinement or reduced presence, as we have experienced during the years 2019-2022: this virtual laboratory would allow students to perform practical sessions from home, on realistic 3D virtual industrial plants, and with the automation tools that they would use in person in the laboratory. This practical teaching could be more flexible and adapted to the student's schedule and availability.
- In the context of normality: the virtualization of the laboratory could be used to create new stations, so that more people could attend the practical sessions simultaneously, and to make practical sessions of longer duration and higher quality. These new stations would be virtual, since adding more physical stations to the Automation Laboratory would be very expensive, and would also cause difficulties due to the physical limitations of the available space. Being able to work with simulated virtual stations would allow the use of a computer classroom as an automation laboratory, where the student can learn to program automation in the same way as on the actual physical laboratory floor. In the same way, students could practice on the 3D model in their personal study time, in order to be able to take advantage of the classroom sessions on the real physical plant in a more optimal way.

For this purpose, we studied several software packages. On the one hand, PLC simulators: Codesys (Codesys, 2023), PLCSIM (PLCSIM, 2023) and OpenPLC (OpenPLC, 2023), and on the other hand, 3D modeling and simulation software for industrial plants: Realvirtual.io (Realvirtual.io, 2023), Factory I/O (Factory I/O, 2023), Emulate3D (Emulate3D, 2023), and Ciros (Ciros, 2023).

These programs present different advantages and disadvantages. With respect to the PLC simulators, we decided to continue using the Siemens Tia Portal integrated simulator, PLCSIM, because we wanted the students to continue learning the use and management of Tia Portal, software that is widely used in the working world. It is a commercial software, but we had already purchased temporary licenses for the students, so the investment was made. With respect to modeling packages, the decision was more complicated. Finally, the two software packages that we liked the most were Factory I/O and Realvirutal.io, because of their benefit-cost ratio, and because they allow us to introduce gamification strategies in the experiences designed with them.

Both programs are specifically oriented to 3D modeling and simulation of industrial plants, allowing the control of these simulated plants with a real PLC and/or a PLC simulator. This aspect was convenient for us, because it allowed us to reuse the models in the two contexts mentioned above (in confinement and adapted presence, the PLC simulator could be used, and in normality, the real PLC could be used directly). The big difference between the two packages is that Factory I/O has been designed to model some of the most common scenarios that can be found in an industrial facility, and the elements and scenes it presents are not editable, while Realvirutal.io is an open framework for visualization and simulation, based on the Unity game engine, which allows the user to create fully customized elements and plants. Finally, we opted to purchase Factory I/O floating licenses because it is a simpler program, the plants are pre-designed, and it is not necessary to know Unity programming to use it.

The next step was the selection, design and implementation of the industrial plants to be modeled, analyzing which were the most appropriate for each subject. The following section will show some of the new practices designed with this tool. While designing these new experiences, we analyzed the feasibility of installing them on a virtual desktop, so that students could access them remotely from home. In the end, it was not necessary to implement this point, because at that moment we went from the confinement state to the adapted face-to-face state (presence in small groups). So we quickly had to install the models of the new practices in the physical laboratory, and connect them to the real PLCs available to us. But it is important to note that the plants are perfectly controllable with the PLC simulator, we had it initially working in this way.

Finally, we evaluated the new practice methodology implemented in the laboratory, a combination of simulated 3D plants controlled by real PLCs. For this purpose, we conducted a usability study, and analyzed the improvement in student learning, taking into account students' feedback. This point will be discussed in detail later.

5 POST-COVID-19 PRACTICE PROGRAM

The practice programs have changed a lot since the introduction of Factory I/O models. In the following subsections we will show some examples of practices, depending on the level of the subject.

5.1 Introductory Automation Courses

The automation practices designed for students starting in the discipline propose the automation of simple plants. The complexity of the practices gradually increases from one practice to the next, and different learning objectives are pursued in each of them. Basically, with these practices, it is intended that the student is able to handle the Tia Portal, make a program, load it into the PLC, run it and debug it. The designed practices are the following ones:

- Session 1: Introduction to Tia Portal, Factory IO and PLC S7-1200.
- Session 2: Automation of a conveyor belt.
- Session 3: Control of a lift.
- Session 4: Control of traffic lights.
- Session 5: Automation of a sorting system for large and small boxes.

Some of these practices are shown in Figures 2-4.

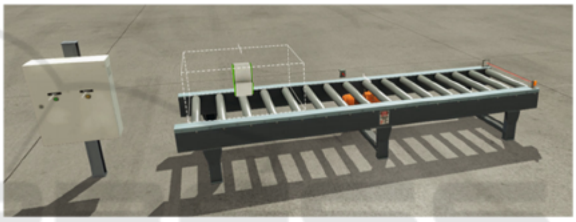

Figure 2: Automation of a conveyor belt.

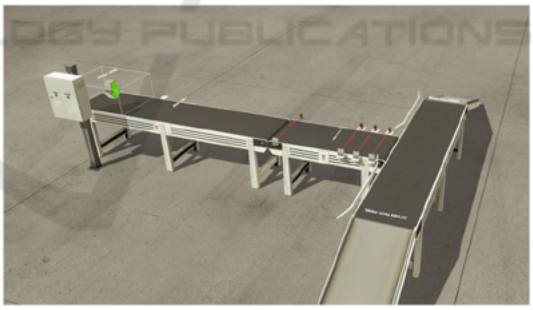

Figure 3: Automation of a sorting system for large and small boxes.

5.2 Advanced Automation Courses

For advanced automation students, the complexity of the models to be automated increases considerably. We assume that the students already know the PLC environment, know how to program it and handle the software tools properly. They are not only required to program the basic operation of the model, but it is also important that they design and implement a GEMMA guide for each plant, and that they test the different

Figure 4: Control of a lift.

states included in the guide on the model. The designed practices are the following ones:

- Automation of a box weighing and color sorting system.
- Automation of a parts assembly system and subsequent classification according to the color of the parts.
- Automation of a box sorting system based on the height of the box.
- Automation of a system for the removal of boxes on pallets and sorting by weight.
- Automation of a parallel parts processing and storage system.
- Automation of a parallel parts processing and color sorting system.

Some of these practices are shown in Figures 5-7.

It is important to clarify that nowadays, with the return of the students to the laboratory, these practices are combined with those performed in the real physical Festo plant. We tried to model the Festo plant workstations with Factory I/O, but it was really difficult to achieve. The Factory I/O program offers non-editable elements (from individual parts to complete stations), which can be combined as the user wishes to build the plants. But in the Festo plant there are stations that are composed of parts not contained in the program libraries. Only stations 2 and 5 could be modeled properly. Figure 8 shows the actual station 5 and its Factory I/O model.

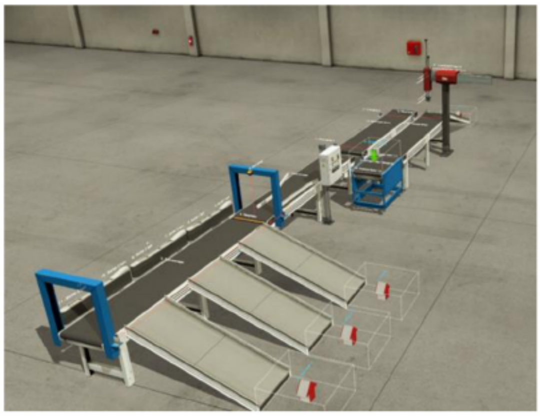

Figure 5: Automation of a box weighing and colour sorting system.

Figure 6: Automation of a parts assembly system and subsequent classification according to the color of the parts.

Figure 7: Automation of a box sorting system based on the height of the box.

As an example of an unsuccessfully modeled plant, we can look at station 3, which consists of a circular rotary table that allows parallel processing of four parts at a time. As nothing similar exists in Factory I/O, we tried to realize a model that would at least allow parallelization of the process (Figure 9). Our goal was to achieve a model that, at the programming level, would be as close as possible to the programming of the real station. However, it can be seen that the visual aspect of the real station and its corresponding model is quite different, and we considered that it was not going to be of great help to the student.

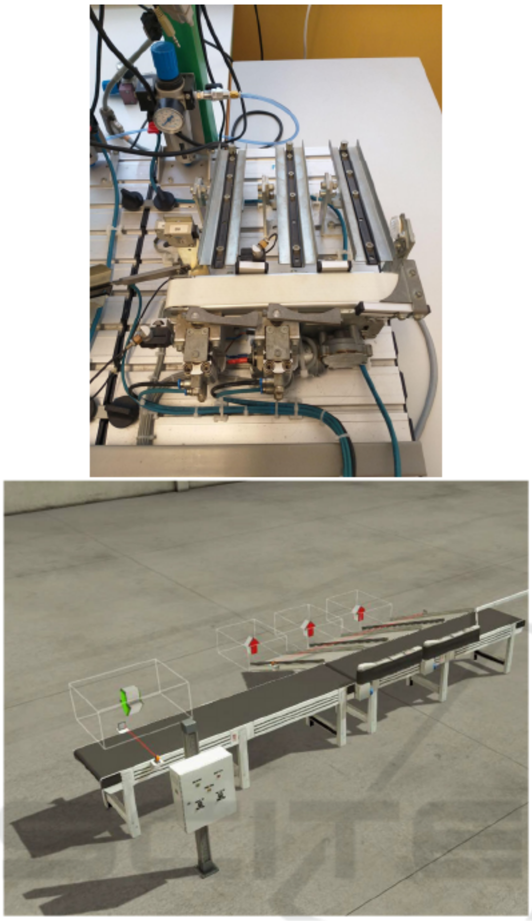

Figure 8: Station 5 of the FESTO plant (up) and its Factory I/O model (down).

Therefore, we have discarded the use of Factory I/O to model the stations of the Festo plant. But we think it is very important to achieve it, so we are currently starting to analyze the Realvirutal.io program, in order to accurately model each station, since this software allows the user to define their own elements and create a customized industrial plant, as if it were the design of a video game, under the Unity environment.

6 EVALUATION OF NEW PRACTICE PROGRAMS DESIGNED WITH FACTORY I/O

After almost two courses using this new educational strategy, based on simulation and gamification, we have observed notable improvements in the acquisition of knowledge and practical skills by students. Specifically, we have found that our effort

Figure 9: Station 3 of the FESTO plant (up) and its Factory I/O model (down).

has been worthwhile, since with the new practical experiences:

- Learning is transformed and dynamized: the practical experience is carried out in a different way, through a fun interactive experience.
- A gamification component is included in the teaching process, which generates a more motivating learning experience.
- The simulated experiences are almost real, with no risk of accidents and environmentally responsible, which are important aspects in the industrial environment.
- Simulated industrial plants can be immersive scenarios of great realism, which brings the student closer to a realistic and professional context.
- Monitoring and evaluation of learning can be a simpler and more transparent process.
- The range of industrial plants to be automated is expanded: generating 3D models of new plants is

always less costly than acquiring these industrial plants physically (which is often unfeasible, and not only for economic reasons).

- Active student learning is encouraged with interactive simulations and their motivation is favored.

We received feedback from the students, through the completion of a satisfaction questionnaire. This questionnaire consisted of the following ten questions:

1. The Factory I/O software made it easier for me to interact with a real PLC.
2. The Factory I/O software has allowed me to apply the KOP programming knowledge acquired in the theory classes.
3. The information provided in the 3D model is effective and helps me to complete the programming of the industrial plant.
4. The Factory I/O 3D models are simple, educational and easy to use.
5. Factory I/O system interface is user-friendly and intuitive,
6. The Factory IO models help to understand how the KOP elements (timers, counters, etc) work.
7. I am able to easily check the validity of my KOP programs on the Factory I/O 3D model.
8. The tool allows me to detect and correct my programming errors quickly.

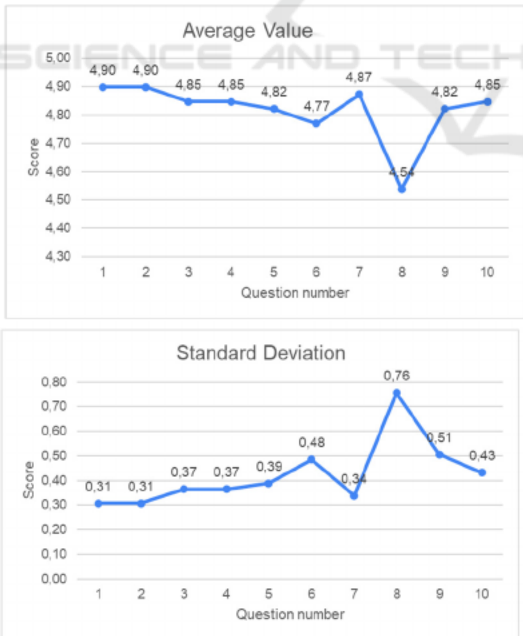

Figure 10: Mean value and standard deviation of the score given by the 39 students who answered the 10 questions posed.

9. The progressive difficulty of the 3D models during the internships seemed to me to be correct and facilitated my learning process.
10. I am satisfied with the use of Factory I/O during the practices.

The questionnaire has been answered by 39 students and the results are shown on a five-point Likert scale. Figure 10 shows the mean value and the standard deviation of the score given by the students for each question. It can be seen that the degree of satisfaction of the students with the new practical sessions is quite good.

7 CONCLUSIONS

The health crisis that occurred with the appearance of COVID-19 affected all areas of our society, including, of course, Education. Traditionally face-to-face teaching suffered especially from the effects of this "hiatus" in our normality. We teachers were forced to change our teaching habits and methodologies to adapt to the new situation. In our experience, the hardest thing was to realize that we could not continue to develop the practical part of our subjects as we had been doing up to that moment. We had to update and make the practical experiences more flexible and accessible remotely, and we had to do it quickly. Therefore, we started working on the virtualization of the laboratory.

The virtual practices must meet the same objectives as the traditional practices taught in the physical laboratory, and be able to transmit the didactic concepts of Automation, such as: knowledge of industrial processes and the elements that integrate them, the design and optimization of the assemblies that make up the process, the programming and control of automatons and, finally, the use of specific software for industrial activities. We believe that the solution we finally arrived at, based on the use of simulation and gamification tools, allowed us to virtualize the laboratory in an adequate way, not only for extreme situations of confinement, but also for normal contexts. Furthermore, the degree of satisfaction of the students with the new practical sessions is quite good.

As mentioned in the introduction, the purpose of this article is not to present a detailed analysis of all the simulation and gamification tools we studied, but to explain what our situation was like before COVID 19, how we faced the change, what we learned in the process, what the new practice programs we are currently following are like, what tools have helped us, and what goals we still have to achieve.

On this last point, our future work is the virtualization of the Festo plant with the Realvirutal.io software. Although we are no longer in a situation of confinement or adapted face-to-face context, we have seen the benefits of introducing this type of practice also in a context of normality, and we believe that having representative models of the stations could greatly enrich the experimentation with this educational plant.

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