Exploring the Implementation of a Remote 3D Printing Lab for ICT Education

Explorando la Implementación de un Laboratorio Remoto de Impresión 3D para la Enseñanza de las TIC

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Abstract- The use of Information and Communication Technologies (ICTs) has become an essential part of modern life, including the increasingly popular 3D printing technology. However, its use in schools can be limited due to factors such as time, material waste, energy consumption, and accessibility. Remote laboratories solve this issue since they provide access to a wide range of resources. This flexibility can benefit students offering a more positive learning experience. In this work, a 3D printing laboratory provided by LabsLand has been employed to test it suitability for ICTs learning on secondary schools. Following a pre/post test design, results have shown that 3D printing remote laboratory help student to better understand the functioning of this technology. Especially, when referring to the orientation in which the piece should be printed. Furthermore, user experience was measured obtaining that students are very satisfied with the experience which make them better learn the technology.

Keywords: ICTs, Remote Lab, 3D printing, Self-learning.

Resumen- El uso de las Tecnologías de la Información y la Comunicación, incluida la impresión 3D, es esencial en la vida moderna, pero su implementación en escuelas se enfrenta a limitaciones como el tiempo, el desperdicio de material y la accesibilidad. Los laboratorios remotos ofrecen una solución al brindar acceso a diversos recursos, mejorando la experiencia de aprendizaje para estudiantes. Se evaluó un laboratorio de impresión 3D proporcionado por LabsLand en centros de secundaria, utilizando un diseño pre/post test. Los resultados demostraron que el laboratorio remoto ayuda a los alumnos a comprender esta tecnología, especialmente en términos de orientación de impresión. La experiencia de usuario también fue medida y los estudiantes mostraron una gran satisfacción, lo que les ayudó a aprender mejor la tecnología. La integración de estos laboratorios remotos puede potenciar la educación en TIC en las escuelas y superar las limitaciones tradicionales.

Palabras clave: TICs, Laboratorio remoto, Impresión 3D, Auto aprendizaje.

1. INTRODUCTION

Information and Communication Technologies (ICTs) have become an integral part of modern life, and having basic knowledge of them is becoming increasingly important. They have transformed the way people communicate, access information, and work. Thus, staying up to date with the latest developments is crucial. Specifically, students should quickly adapt to changing circumstances to build themselves a successful future (Froyd et al., 2012). Among the latest cutting-edge technologies, 3D printing has been increasingly used for mass customization and production of open-source designs. 3D printing is a very useful technology that provides great customization and efficiency, while also offering new opportunities for innovation and creativity.

When teaching the foundation of Science, Technology, Engineering and Mathematics (STEM) fields, students' experimentation is a key part of education. However, 3D printing laboratories entails several limitations that must be taken into account:

- <u>Time</u>: 3D printing can be a slow process, especially for large or complex objects. This can make it impractical for school teaching where classes are limited in time.
- <u>Material waste</u>: 3D printing can generate a significant amount of residues, particularly in the form of support structures and failed prints. This can contribute to environmental pollution and resource depletion.
- <u>Energy consumption</u>: 3D printing can consume a lot of energy, particularly for larger or more complex objects. This can contribute to greenhouse gas emissions and climate change.
- <u>Accessibility</u>: many schools and universities may not have the funding or resources to provide students with access to the latest equipment and technology, which can increase the inequality between students.

Remote laboratories provide a cost-effective, accessible, safe, reproducible, flexible, and eco-friendly alternative for students to enhance their learning process. A remote laboratory platform allows the use of the technology from a remote place,

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instead of every school having its own infrastructure and maintenance. That means that the laboratory is real, and the student accesses it remotely. These laboratories can be divided into real time, where students book a time slot to use the technology, or ultra-concurrent, where the laboratory experience is recorded a sufficiently large number of times, providing a real experience to the student. Among all the benefits of remote laboratories, they help to improve the effectiveness of the learning process, reaching more students. Moreover, when an ultra-concurrent laboratory is considered, this means a lower cost of energy, material, and time. It should also be noticed that they allow students to complete experiments and assessments at their own pace and schedule, which can help to reduce stress and anxiety and promote a more positive learning experience. Additionally, remote laboratories can be designed to include mechanisms of auto evaluation, which can provide students with immediate feedback on their progress and help them identify areas where they may need additional support. In conclusion, remote laboratories allow individuals to acquire knowledge and skills independently, adapt to changes, become more self-sufficient and develop critical thinking and problem-solving skills. It is essential for personal growth, career advancement, and lifelong learning (González González, 2010).

LabsLand, a spin-off of University of Deusto (Spain), is presently the only company globally that provides remote experiments as a service (Orduña et al., 2018). It provides a network for universities and research centers to remotely access their laboratories and the ones created by others. Currently, LabsLand offers access to over 50 remote experiments from 17 different countries across the globe. Some of the starting laboratories that were created included Galileo's pendulum, radioactivity, freefall, planarians (planarians and beverages), and basic circuits. In this work, the '3D Printer' laboratory (Università del Salento, n.d.) will be employed.

The objective of this work is to create and test a teaching methodology using remote laboratories to enhance student involvement in their learning process. LabsLand – 3D Printer laboratory (Università del Salento, n.d.) has been employed with 16-17 years old students. Learning improvement has been assess through an experimental design O-X-O known as pre/post-test (Campbell & Stanley, 1966). Finally, results have been analyzed using a statistical analysis to evaluate the statistical significance of the obtained results.

2. Context & description

The experiment was conducted at a secondary school located in the capital of the island of Gran Canaria, in the municipality of Las Palmas de Gran Canaria. The school is well equipped with new technologies. The institution offers Baccalaureate education (7 sections per grade) and Vocational Training (10 programmes). In this work, we have focused on the first year Baccalaureate (grade 11) students distributed into two groups, as shown in **Table 1**. Specifically, the activity has been carried out in the subject ICTs of 1st year of Baccalaureate. Most of the students come from private schools, some of which are public funded. Therefore, the socio-educational context is of a medium-high level, with a medium-middle income level and medium-high educational expectations.

Table 1. *Information of the remote laboratory experiment.*

	Group 1	Group 2
Subject	ICT	
Weeks	2	
Age	16-17 years old	
Number of students	20	20
Teacher's experience	No experience	
Students' experience	2	3

A. Didactic technology and activities

To carry out the activities, an ultra-concurrent 3D printing laboratory (Università del Salento, n.d.) developed by LabsLand (Orduña et al., 2018) was employed. The educational activities of this work are centered on the self-learning ability of the students. First, students are encouraged to locate the remote laboratory using Google Maps or a similar tool. In this specific case, the 3D printer laboratory is based on the University of Salento in Lecce, Italy. Next, students can observe that the experiment is focused on 3D printing of the letter 'A' by choosing different parameters (orientation, thickness, temperature or supports) to configurate the printer (**Figure 1**). There are a total of 90 possible combinations that can be tested, however, they will not be able to test all of them in one session. Thus, random choices of parameter would be made. Finally, students can access an observation step where they can see from different angles how the piece is being printed (Figure 2). Once the A is printed, students must evaluate its quality and repeat trying different parameters.

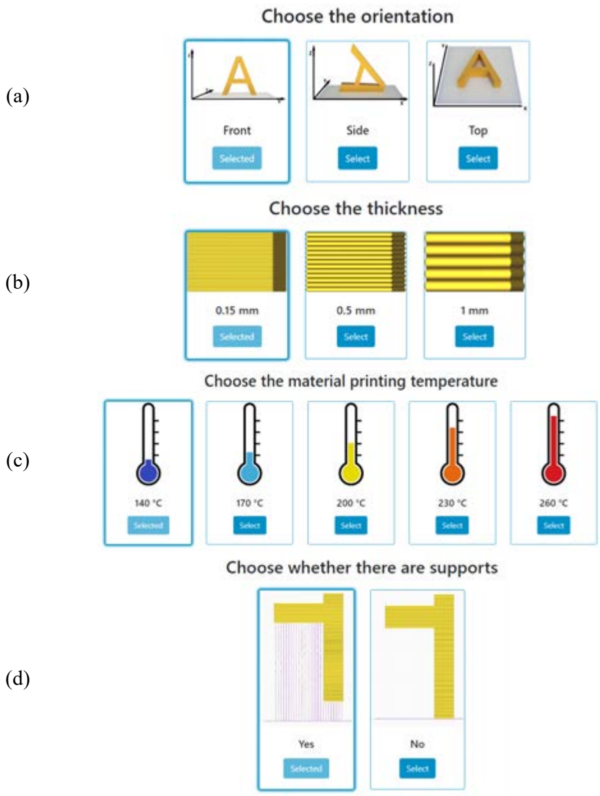

***Figure 1**. Selection of different configurations of the 3D printing. (a) Orientation. (b) Thickness. (c) Temperature. (d) Supports.*

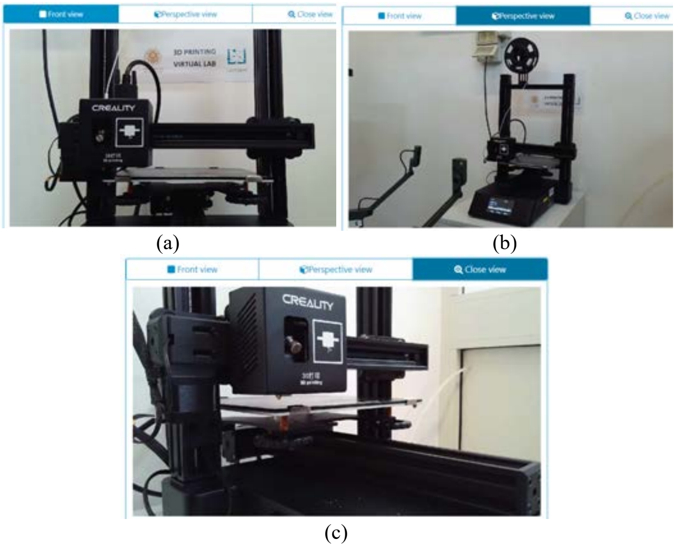

Figure 2. Selection of different configurations of the 3D printing. (a) Front view. (b) Perspective view. (c) Close view.

Finally, students collect the parameters used, along with their corresponding results. **Figure 3** shows two proofs performed, where the first shows that the student did not choose the correct parameters, while the second shows that the parameters were chosen correctly. They will sort the different 3D printed pieces according to their quality, thus identifying the best parameters for 3D printing. Moreover, a debate will be held to determine the optimal settings for 3D printing and how the results can be extrapolated to other types of objects.

Proof	Orientation	Thickness	Temperature	Support	Result
1	Lateral	1 mm	260 ºC	No	
2	Superior	0.15 mm	200 ºC	No	

***Figure 3**. Student summary table showing the results for each combination of parameters.*

B. *Research Methodology*

To measure the effectiveness of the experiments, the experimental design O-X-O known as pre/post-test (Campbell & Stanley, 1966) was employed. They took the same questions and were made before and after the 3D printing laboratory took place(Quintana-Quintana, 2023). Finally, to test the experience students when using a remote 3D printing laboratory, the UXQ4RLv1 questionnaire was also employed (Cuadros et al., 2021).

Study data were collected using REDCap (Research Electronic Data Capture) tools hosted at Universidad de Las Palmas de Gran Canaria - Instituto Universitario de Microelectrónica Aplicada. REDCap (Harris et al., 2019) is a secure, web-based software platform designed to support data capture for research studies. It provides an intuitive interface for validated data capture, audit trails for tracking data manipulation and export procedures, automated export procedures for seamless data downloads to common statistical packages and, procedures for data integration and interoperability with external sources.

Afterwards, a data analysis was performed to assess the statistical significance of the obtained results. Statistical analysis shown in Results has been performed using the SciPy Python library, with a confidence level of 95% in all cases. Due to the discrete nature of the answers of the questionnaire, they were treated as 'correct' or 'incorrect'. Since the questions before and after the experiment were the same, and they were answered by the same group of students, these answers can be considered as paired proportions. To evaluate if this experiment influenced in the student's answers McNemar's $\chi 2$ test was performed for every question independently. The null hypothesis of this test is that the event between the two answers (i.e., the 3D printing remote laboratory session) does not influence the student's answer. Hence, p-values lower than 0.05 in each question would mean that this experiment has influenced the student's answer (Hazra & Gogtay, 2016). Furthermore, two exclusions criteria were applied for this statistical analysis: first, only students that answered all questions were included: second, students that had previous experience with the 3D-printing technology were excluded, since this initial session will not expectedly show something new to them. At the end, 30 students were included in this analysis.

3. RESULTS

Figure *4* illustrates that, except for the case of the first question, the number of correct answers always increased after the remote laboratory session. It is remarkable the case of the second question regarding the importance of the 3D-printer orientation in the result, where there was an increase of nearly a 50% of the amount correct answers. Besides, this result was statistically significant ($p<0.05$) Hence, this short session helped the students to understand the importance of one of the main parameters in the result of the final product.

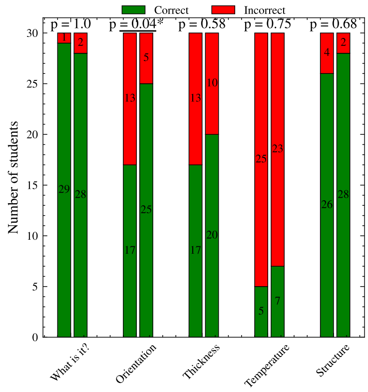

Figure 4. *Number of correct and incorrect answers before (left) and after (right) the experiment. On the top of each pair of bars, the p-value of each question is indicated.*

Regarding the satisfaction of the students with the remote laboratory,

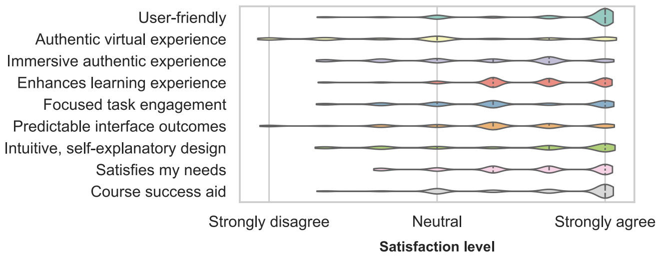

Figure **5** shows that they were engaged with the sessions. This engagement would likely influence their learning process positively. Only two questions were answered with the most negative possible answer: one, regarding the authenticity of the virtual experience. The other one, regarding the predictability that the remote laboratory session results.

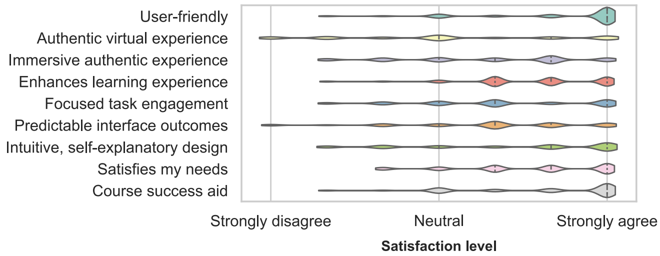

Figure 5. *Violin diagram containing the student's answer to the satisfaction questionnaire. (1: strongly disagree; 4: neutral; 7 strongly agree).*

4. Conclusions

ICTs have become increasingly important in modern life, necessitating basic knowledge of these technologies. Among them, 3D printing has emerged as a transformative tool for mass customization and open-source design production. However, traditional 3D printing laboratories face limitations in terms of time, material waste, energy consumption, and accessibility. To address these challenges, in this work we have employed LabsLand laboratories. Specifically, the LabsLand-3D Printer laboratory from the Università del Salento was utilized to create and test a teaching methodology aimed at enhancing student engagement and learning outcomes. A pre/post-test design and a questionnaire assessing student experience were performed. At the end, although only one question was statistically significant, it was appreciated that the remote laboratory session showed improvement in students' knowledge. Future work includes increasing the number of sessions and the number of students involved in this experience. This will probably show better results, directly related to an enhancement of the student's learning process.

In conclusion, the integration of remote laboratories, such as the LabsLand-3D printer laboratory, enhances student engagement and learning satisfaction in ICT education. It promotes sustainability by reducing the time, material waste, and energy consumption associated with traditional 3D printing laboratories, contributing to a more environmentally conscious approach and efficient resource utilization. Furthermore, remote laboratories empower students to develop essential skills for success in the digital era, learning how to adapt, become self-sufficient learners, and cultivate critical thinking and problem-solving skills. It is also remarkable the transferability of this methodology to other educational contexts. Remote laboratories provide global access through online platforms, enabling educational institutions to implement this methodology and benefit a larger number of students worldwide. In this way, since this experiment has been successful, it is suggested that educational institutions consider incorporating remote laboratories in their ICT education programs to promote active student participation and improve learning outcomes. This will help further research since it is needed to explore and evaluate different approaches and tools for remote laboratories that suit specific needs and contexts.

In summary, remote laboratories offer a sustainable, transferable, and effective alternative for enhancing ICT learning. By integrating these solutions, educational institutions can strengthen student training, preparing them to tackle the challenges of the digital world and develop key skills for personal and professional success.

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References

Campbell, D. T., & Stanley, J. C. (1966). Experimental And Quasi-Experiment Al Designs For Research. Houghton *Mifflin*.

Candelas-Herías, F. A., Torres, F., Gil, P., Ortiz Zamora, F. G., Puente Méndez, S. T., & Pomares, J. (2003). *Evaluación del impacto de los laboratorios virtuales con acceso remoto en el aprendizaje de las prácticas de estudios de ingeniería*.

Cuadros, J., Serrano, V., Garcia-Zubia, J., & Hernandez-Jayo, U. (2021). Design and Evaluation of a User Experience Questionnaire for Remote Labs. *IEEE Access*, *9*, 50222–50230. https://doi.org/10.1109/ACCESS.2021.3069559

Froyd, J. E., Wankat, P. C., & Smith, K. A. (2012). Five Major Shifts in 100 Years of Engineering Education. *Proceedings of the IEEE*, *100*(Special Centennial Issue), 1344–1360. https://doi.org/10.1109/JPROC.2012.2190167

González González, M. T. (2010). El Alumno Ante La Escuela Y Su Propio Aprendizaje: Algunas Líneas De Investigación En Torno Al Concepto De Implicación. *Revista Iberoamericana Sobre Calidad, Eficacia y Cambio En Educación (REICE)*, *8*(4), 10–31.

Harris, P. A., Taylor, R., Minor, B. L., Elliott, V., Fernandez, M., O'Neal, L., McLeod, L., Delacqua, G., Delacqua, F., Kirby, J., & Duda, S. N. (2019). The REDCap consortium: Building an international community of software platform partners. *Journal of Biomedical Informatics*, *95*, 103208. https://doi.org/10.1016/j.jbi.2019.103208

Hazra, A., & Gogtay, N. (2016). Biostatistics series module 4: Comparing groups - categorical variables. *Indian Journal of Dermatology*, *61*(4), 385. https://doi.org/10.4103/0019-5154.185700

Orduña, P., Rodriguez-Gil, L., Garcia-Zubia, J., Angulo, I., Hernandez, U., & Azcuenaga, E. (2018). *Increasing the Value of Remote Laboratory Federations Through an Open Sharing Platform: LabsLand* (pp. 859–873). https://doi.org/10.1007/978-3-319-64352-6_80

Quintana-Quintana, L. (2023). 3D Printing Questionary. In *Zenodo*. Zenodo. https://doi.org/10.5281/zenodo.8036467

Università del Salento. (n.d.). *3D Printer*. LabsLand. Retrieved May 10, 2023, from https://labsland.com/en/labs/3dprinter