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Educational Experiences in Engineering in the COVID-19 Era and Their Comparative Analysis: Spain, March-June 2020

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***Abstract*—**In March 2020, in Spain, a sanitary and unexpected crisis caused by COVID-19 was declared. All of a sudden, all degrees, classes and evaluation tests and projects had to be transformed into online activities. However, the chaotic situation generated by a complex operation like that, executed without any well-established procedure, led to very different experiences and, finally, results. In this paper, we are describing three experiences in two different Universities in Madrid. On the one hand, the Technical University of Madrid, a public university with little experience in online education was considered. On the other hand, Alfonso X el Sabio University, a private university with more than five years of experience in online teaching was involved. All analyzed subjects were related to computer engineering. Professors and students answered a survey and personal interviews were also carried out. Besides, the professors' workload and the students' academic results were also compared. From the comparative analysis of all these experiences, we are extracting the most successful strategies, methodologies, and activities. The recommendations in this paper will be useful for courses during the next months when the sanitary situation is still affecting an educational organization. While, at the same time, they will be considered as input for the upcoming digitalization process of higher education.

***Keywords*—**Educational experience, online education, higher education digitalization, COVID, Spain

I. Introduction

IN the last twenty years, higher education has transformed from a very traditional system (where in-person classes were the basis of the educational process) to an innovative ecosystem, where many different paradigms and theories focused on improving the students' learning and experiences have been proposed and implemented.

Actually, nowadays universities and other higher education institutions are offering degrees, masters and education programs where different methodologies are employed [1]: from traditional in-person methodologies, to blended leaning and online teaching. This tendency affects all institutions around the world: from the Pacific area to the United States and the European Bologna space. However, not all education spaces are integrating these new approaches in the same way. For example, in the Spanish higher education system, although some Learning Management Systems (LMS) such as Moodle are being extensively implemented [2], most degrees, and even Universities are specialized and focused on only one methodology. In that way, we can find courses and institutions where all subjects are organized according to an online method [3], while other universities are still mainly employing the traditional presential classes and exams as basic teaching instrument. Thus, some universities (as Alfonso X el Sabio University) have an important knowledge and experience about online teaching and learning, while others such as Technical University of Madrid are not even provided with the required software tools for such activities [4].

In this context, in March 2020, unexpectedly, the regional governments and, later, the national government declared the emergency state in Spain, because of the sanitary situation due to COVID-19 [5]. Suddenly, a very hard lock-down was established and all students and professors were forbidden to be on the streets, to work or to study. Online teaching was imposed by national law and a four-month (since March 2020 to June 2020) social and sanitary crisis started. Although professors or student were not allowed to physically attend the facilities of the Universities, no additional guideline, recommendation, or instruction was provided. Each University could manage the situation independently and according to their own resources [6]. Obviously, this decision led to a heterogenous catalogue of experiences and methodologies, whose real performance is still (largely) unknown.

Although some decisions were common to all institutions, such as the cancellation of practices in hospitals, industry or offices, other solutions were totally different, and even divergent and, sometimes, polemic [7]. In general, universities with a relevant knowledge of online learning rapidly extended their existing tools to all subjects, degrees and professors offering formative courses to all professors since the beginning. A global strategy, besides, was deployed for the whole institution, but particularities and differences among subject or degrees were totally ignored. That was the case of Alfonso X el Sabio University (hereinafter, UAX). On the contrary, universities focused on traditional methodologies (as Technical University of Madrid, hereinafter, UPM) declared the autonomy of professors. In that way, all particularities of

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subjects and students could be considered, but also an anarchic climate was created, and more than four weeks were necessary to provide professors with the first basic online communication tools and formative courses.

Informal observations show advantages and disadvantages of both approaches, and a deeper analysis is needed to extract sound conclusions. This paper contributed to fill this gap. A large catalogue of different subjects and universities with different strategies for teaching during the COVID emergency have been studied and compared using statistical tools. The final objective is to conclude which methodologies and approaches have been more successful so they should be considered for future similar events or for the upcoming higher education digitalization process.

In this initial paper, nevertheless, only the first results regarding three subjects related to computer engineering are described and presented. Two of these subjects ("Network and System Cybersecurity" -SSR- and "VHDL programming" -PHR-) were supported by UPM; while the third subject ("Digital Systems" -SD-) was supported by UAX. In order to analyze the performance of the different strategies followed in these subjects, students and professors answered a survey about the experience. A Likert scale is employed to allow a systematic and statistical analysis of the data. In addition to the academic results, the professors' and students' workload have been also compared.

The rest of the paper is organized as follows. Section II describes other previously reported educational experiences during the lock-down and COVID-19 crisis. Section III presents the three subjects under study, including the strategies for teaching, evaluation, and tutorial action. Section IV describes the methods and materials for the scientific analysis and comparative analysis of the different experiences. Section V shows and discuss the results and Section VI concludes the paper.

II. Previously Reported Experiences about COVID and Education

Because of the relevance of the topic, the urgent need of responses (as the COVID-19 crisis is still running in 2021) and the great interest of such an unusual situation, many works of education in the COVID era have been reported; despite how little time has passed since the crisis' beginning.

In general, as it is the most challenging situation, experiences related to medical education are the most common [8]. However, because of the lack of time, these works are only descriptive, without any quantitative or methodological study. Papers presenting the platforms and methodologies that may be used to teach medicine in this context may be found [9]. Besides, qualitative descriptions about how the pandemic is affecting medical education and potential solutions have been also reported [10]. Similar works have been also published related to science education [11], cardiothoracic education [12], general education issues [13] or orthopedic education [14], or some specific education systems, such as in The Philippines [15] or India [16].

Very few authors have already provided data or scientific analyses of the situation. Works on this topic are still reports with raw information about the experience [17], or initial comparative analyses where only qualitative variables are analyzed [18]. Besides, these works are focused on a very general context (usually global), where it is very difficult to assume all people under study present similar characteristics, culture, socioeconomic level, etc. That reduces the relevance and impact of this approach.

Finally, in the last months of 2020 and first part of 2021, a sparse number of works are offering the initial methodological and scientific results about the COVID-education experiences in the context of cohesive populations. Studies related to India [19] showed the success of online but asynchronous tools, such as Google Classroom (because of the Internet connectivity problems in the country). In addition, and also in India, the success of virtual laboratories in engineering education during COVID crisis [23] has been reported. In the same way, similar conclusions are obtained by American authors when analyzing telesimulation-based education [24]. In Turkey, using the photovoice methodology, authors have analyzed how technological barriers affect students' results after COVID crisis and online methodologies (and conclusions show the impact is higher than ever) [22]. Other works, focused on Eastern Europe, showed that the students and professors' visions are almost coincident regarding the performance of the different methodologies [20]. Similar results are reported by Spanish authors [7]. Finally, works analyzing the situation in Germany [21] showed how a relevant decreasing in the interaction level between professors and students was caused independently from the employed methodology.

Nevertheless, none of these initial works is focused on the engineering education; and this paper aims to fill this gap.

III. Experiences Under Study

In this section we are describing the educational experiences conducted in each one of the studied subjects. Namely: "Network and System Cybersecurity" (SSR) and "VHDL programming" (PHR) integrating the computer engineering degree at UPM; and "Digital Systems" (SD) integrating the Computer engineering degree at UAX. Five basic elements are discussed: (1) the context (social and educational), (2) the teaching methodology, (3) the tutorial action, (4) the evaluation system and (5) the main advantages and disadvantages. Subsection III.A, III.B and III.C describe aspects of each subject.

A. Network and System Cybersecurity (SSR)

SSR is a subject focused on cybersecurity topics. Firewalls, applied cryptography, security in wireless networks, virtual private networks (VPN) and hacking techniques are the units addressed in this subject. The course lasted 16 weeks from February 2020 to June 2020. Table I shows the schedule and temporal organization of this subject. As can be seen, in March 2020 (when the lockdown was declared), two units (firewalls and applied cryptography) were already presented. The reported experience, thus, refers to the remaining units.

TABLE I
ORIGINAL SCHEDULE FOR SSR

WEEK	Unit	Week	Unit
February 3rd	Applied Crypto	March 30th	VPN
February 10th	Applied Crypto	April 13th	VPN
February 17th	Firewall	April 20th	VPN
February 24th	Firewall	April 27th	Secure network
March 2nd	Hacking	May 4th	Secure network
March 9th	Hacking	May 11th	Secure network
March 16th	Hacking	May 18th	Secure network
March 23rd	EXAM #1	May 25th	EXAM #2

This subject is part of the third course in the Computer Engineering degree at UPM. The subject, typically, includes 60 hours of presential classes and six European Credits (ECTS).

Seventy-two students were enrolled in the subject; 83% of them were male and only 17% of them were female. Only 12% of students failed the subject in the past and in March 2020 were enrolled for second time. In general, because of the geographical position of the University, students in this subject belong to a medium-low socioeconomic group. Many of them do not have access to their own computer or a broadband internet connection.

After declaring the lockdown, and using the educational contract methodology, the new schedule, tutorial actions and evaluation system was negotiated between professors and students.

During the lockdown all classes were maintained, although their original schedule was changed, in order to help students to share their computers with online workers at the same home. All classes were moved from 13h-15h to 16h-18h. Online teaching was developed using Skype enterprise in a Windows ecosystem. All classes were recorded and shared with students through the Youtube platform, and the official Moodle platform provided by the university.

Tutorial actions were performed using five different channels and tools, with the purpose of ensuring that professors and students could always interact. Students could contact professors asynchronously using the email and a Telegram channel specifically created for the subject. For synchronous sessions Microsoft Teams, Skype Enterprise and Discord platforms were available. Weekly, professors were available there for two hours, although other appointments were possible after contacting with professors.

The evaluation system was totally changed. Both planned exams (see Table I) were cancelled as the sanitary conditions (even in March) were expected to be bad for long weeks. As replacement, two practices related to firewalls and applied cryptography based on PacketTracer scenarios were announced. These practices substituted the first exam (EXAM #1). The second exam (EXAM #2) was substituted by a final project working all contents and competencies assigned to the subject. In addition, all students should enroll and answer all challenges in the picoCTF 2019 platform (an online platform containing cybersecurity activities). In order to help students during this extraordinary crisis, evaluation was flexible and particular cases were individually analyzed. Furthermore, all evaluation criteria were published when the lockdown initiated using rubrics (see Fig. 1).

Evaluation topic	Low (0%)	Medium (50%)	Good (75%)	Excellent (100%)
Results (25%)	No exercise has been solved or the student has not event try	25% problems solved and have tried the other ones	50% problems solved and have tried the other ones	All problems solved
Daily work (25%)	Negligible work	Late start, but the student tried hard to catch up	Irregular works along the course	Regular work along the course
Knowledge (50%)	Cannot explain how the problems are solved	Know some details about the solution but not the whole approach	Can explain the solution but with some mistakes and minor errors	Know the entire solution, its limits, problems and able to explain it

Fig. 1 Evaluation rubric in SSR and PHR

Informal observations showed that the students are highly satisfied with the experience even though the professors reported an extraordinary workload creating tutorial actions.

B. VHDL Programming (PHR)

PHR is a very practical subject. Basically, it consisted of a laboratory where students must perform a project using VHDL (Very High-Speed Integrated Circuit Hardware Description Language) and FPGA (field-programmable gate array) technologies. The project is personal, and students must make a proposal during the first weeks in March.

Students are allowed to work in groups with other three or four colleagues (maximum), although individual projects are also possible. The projects must be innovative and show the creativity and teamwork capabilities of students. Students have four weeks to learn about VHDL and 12 additional weeks to develop the project. The entire subject requires 16 weeks. In March 2020, the initial four weeks focused on learning VHDL were over; so, the experience only affects the development of the final project.

Typically, students attend the laboratory 60 hours, according to a subject valued with six European Credits (ECTS).

Sixty-three students were enrolled in the subject, of which, 69% were male and only 31% of them were female. Only 4% of students failed the subject in the past, and in March 2020 were enrolled for second time. The socio economical background of students in this subject is similar to the described one in Section 3.1, as both subjects belong to the same degree and university.

Initially, classes were cancelled for two weeks, and, during the third week of March, they continued in the same schedule (11h-13h) through the Microsoft Teams platform. Classes were not recorded, and, by default, they were not synchronously followed by professors. If students desired a synchronous session with professors, they should previously request it using the chat in the platform. To allow students to learn in an autonomous manner, all of them were provided with learning materials in PDF format and a virtual machine with all the required software, such as ModelSim.

TABLE II
ORIGINAL SCHEDULE FOR SSR

ACTIVITY	Weight (percentage)
Project proposal	10%
Code	30%
Project memory and report	40%
Project presentation	20%

The tutorial action, in this case, was limited to synchronous sessions through the Microsoft Teams platform, which must be requested by students by email. Weekly, professors invested six hours to the tutorial action. Exceptionally, students could contact professors by email for small questions or administrative issues.

The evaluation system did not suffer any change. The final project was the only evaluation activity, although some sub activities within this project were defined (see Table II).

Contrary to other past courses, in 2020, the physical and hardware implementation of the project was not required nor evaluated. No particular or exceptional circumstance was allowed. All criteria were communicated to students as soon as possible using the official Moodle platform provided by the university. Evaluation rubrics were employed to do that (see Fig. 1).

Informal observations show that, with this approach, professors' and students' workload did not change despite of the lockdown. That is its main advantage. In contrast, the main disadvantage was that students found the learning process harder, and the academic results are worse than in previous years.

C. Digital Systems (SD)

Contrary to all previously described experiences, SD is a theoretical subject. This subject includes seven units: Boolean algebra, logic gates, logic functions, combinational circuits, flip-flops, sequential circuits, programmable circuits. The course lasted 14 weeks since middle February 2020 to middle June 2020. The organization of this subject is totally different from all previously described experiences. Six online webinars are broadcasted, with a synchronous connection among professors and students. Table III shows the schedule for this subject.

TABLE III
ORIGINAL SCHEDULE FOR SD

DATE	Webinar (units)
March 3rd	Boolean algebra, logic gates
March 17th	Logic functions
March 31st	Combinational circuits
April 14th	Flip-flops
April 28th	Sequential circuits
May 12th	Programmable circuits
May 22nd	Presential class
May 29th	EXAM

These webinars are employed to present the different units and no presential classes are planned. In addition, a final presential class and a presential exam was also planned.

This subject was integrated into the Information Technologies (IT) degree at UAX. It is a subject for students in the first course. It is computed that students should invest around 180 hours to learn and pass the subject; according to the six ECTS it has associated.

Twelve students were enrolled in this subject in the course 2019-20. Only two of them (17%) were female. For all students it was the first enrollment in the subject. The socioeconomic context of students, in this case, is also very different. They belong to a high-class sector of society, supported by the geographic placement of the University.

During the lockdown, webinars maintained their format. Classes were supported by platform Blackboard Collaborate, officially provided by the university. All classes were recorded and kept available at the official virtual campus. Presential classes were cancelled and took place through the Blackboard platform. The schedule of all these activities did not suffer any change.

Tutorial actions in this subject were conducted through two different channels: the message platform and the Blackboard collaborate platform. The university provided professors and students with a communication platform based on asynchronous messages to support the tutorial action. Professors answered messages in this platform in less than 48 hours. In addition, professors were available weekly for three hours, in two sessions of on hour and a half, in a specific Blackboard Collaborate session. All these tools were integrated in the official virtual campus.

Evaluation did not suffer any change either. Students should answer, every unit, an online questionnaire and test related to the theoretical basis of the unit. These questionnaires may be answered at any time before the final exam. Besides, seven practical exercises related to every unit are also required. These exercises must be solved offline, using the provided documentation. The solution is submitted through the virtual campus. Finally, a global final exercise (working competencies associated to all units) is also essential to pass the subject. The last element was a final exam. The exam was distributed as a PDF file through the online campus and answered by students synchronously while connected with the professor using a Google Meet session. Google Meet allows creating a full mosaic with all students, viewing all of them at the same time. Solutions were submitted by students using the online campus at the end of this session. Table IV shows the composition of the evaluation system in SD.

TABLE IV
EVALUATION COMPOSITION FOR SD

ACTIVITY	Weight (percentage)
Online tests	5%
Exercises	10%
Final exercise	25%
Exam	60%

The main advantage of this approach is the smooth transition between a standard methodology and the "crisis methodology". However, the main disadvantage, in this blended methodology,

is that presential classes are essential and, informal observations, are showing a full online teaching is affecting the students' academic results

IV. Comparative Analysis: Methodology

The proposed comparative study is based on three basic information sources. On the one hand, academic results of students were collected and analyzed. Besides, students and professors answered a survey about their experience in the different subjects, regarding four basic elements (teaching, tutorial actions, evaluation, and workload). Finally, the professors' official workload reported into the official application was also acquired and analyzed. All this information was compared using statistical tests and tools and, when possible, compared also with information about previous courses.

In this study we are not evaluating the performance of the teaching methodologies or the evaluation methods independently, but we are analyzing which response to the educational and social crisis, and approach to the in-person-to-online transition is more adequate. Thus, we are considering subjects and different approaches as a whole, with all their differences. However, through the surveys and interviews, we will try to learn which elements and causes made the different approaches a success or not.

The experiment described in this paper was planned, guided, monitored and evaluated by its authors (hereafter experts), who have more than five years of experience in knowledge management, educational innovation and data analysis.

Academic results were acquired from the official tracking platform provided by the university. Results from the current COVID-affected course and from the previous year were collected.

Nevertheless, the main information source for this study was the survey. Students and professors participating in all the previously described subjects were asked to answer a survey with 53 questions. All these questions were based on a Likert (1-5) scale and addressed four basic topics: the teaching methodology (17 questions), the tutorial action (10 questions), the evaluation system (19 questions) and the workload (seven questions). Questions about context information are not included in this description. In order to ensure that participants do not answer the survey randomly, most questions in the survey only address six basic research questions, two related to teaching, another two questions related to evaluation, and one question for every remaining topic (tutorial action and workload). These basic research questions were:

- Teaching#1 (T#1): Did you feel the number of classes was enough?
- Teaching#2 (T#2): Was the quality of teaching adequate?
- Evaluation#1 (E#1): Did you feel the evaluation was fair and measure your real learning?
- Evaluation#2 (E#2): Do you feel the evaluation was like in a normal course?
- Tutorial#1 (TA#1): Was the interaction professors-students correct?
- Workload#1 (W#1): Was your workload as usual?

Additionally, some personal interviews were carried out, in order to collect enriched comments regarding all the experiences.

Although all people involved in the subjects under study were asked to answer the survey, not all of them did it. Table V and Table VI present the final and real participants on that survey.

As can be seen, the number of professors is low, and obtained results must be carefully considered. Therefore, that information was used to complement the students' responses, but no statistical test was conducted using the professors' surveys (because of the lack of participants).

TABLE V
Participants (Students) in the Survey

Subject	Participants	Mean age	Standard deviation in age	Female percentage	Percentage of second enrollments
SSR	54	22.5	2.3	22%	3%
PHR	49	23.7	1.3	34%	2%
SD	9	29	4	19%	0%

TABLE VI
Participants (Professors) in the Survey

Subject	Participants	Mean age	Standard deviation in age	Female percentage
SSR	2	46	16	0%
PHR	3	39	6	33%
SD	1	29	--	0%

Finally, in all universities in Madrid a Global Quality Management system controls and monitors the real and official workload of professors. These data were also considered, regarding the current COVID-affected course and the previous ones.

All the participants were treated anonymously by experts. No personal data related to the students' or professors' identification were stored or diffused outside the official platforms. All the experiments were performed under the conditions of respect for individual rights and ethical principles that govern research involving humans.

All data were introduced in MATLAB 2019b software in order to perform the statistical analysis of the collected information. In order to compare data in a scientific manner and extract sound conclusions we are employing a Mann-Whitney U test to evaluate the different experiences. The Mann-Whitney U test is a nonparametric test of the null hypothesis that two samples come from the same population against an alternative hypothesis, comparing the mean values of the two samples. It is used to evaluate if two different data populations are similar or different (higher or lower). The p-value indicates the significance level of Mann-Whitney U test.

V. Comparative Analysis: Results and Discussions

The first experiment was focused on the academic results of students. Students were divided into four quartiles according to their academic performance, being GQ1 the group of people with marks in the first 25% of the available range; and GQ4 the

group of people with marks in the lowest 25% of the available range. Table VII shows the results.

As can be seen (informally), results in SSR improved significantly. The implementation of an innovative project-oriented evaluation, despite the lockdown, highly benefited students. On the contrary, academic results in SD suffers a sight decreasing caused by the implementation of a full online methodology. In PHR, no relevant difference is observed heuristically.

TABLE VII
ACADEMIC RESULTS: DISTRIBUTION OF STUDENTS IN QUARTILES

Subject	Year	GQ1	GQ2	GQ3	GQ4
SSR	2019	4.9%	72%	20.1%	3%
	2020	82.3%	11.4%	6.3%	0%
PHR	2019	0%	92%	4.6%	3.4%
	2020	0.5%	91%	8.5%	0%
SD	2019	21.2%	78.8%	0%	0%
	2020	16%	84%	0%	0%

In order to statistically compare the academic results, the Mann-Whitney U test was carried out. Results are showed in Table VIII.

TABLE VIII
STATISTICAL COMPARISON OF THE ACADEMIC RESULTS

		SSR		PHR		SD	
		2019	2020	2019	2020	2019	2020
SSR	2019	--	***	*	**	**	**
	2020	***	--	***	***	**	**
PHR	2019	*	***	--	NS	**	**
	2020	**	***	NS	--	**	**
SD	2019	**	**	**	**	--	*
	2020	**	**	**	**	*	--

NS not significant; * significant at $p < 0.05$; ** significant at $p < 0.005$; *** significant at $p < 0.001$

As can be seen, fully online methodologies have no impact in practice subjects (PHR), but there is a relevant decreasing in the students' performance in theoretical subjects (SD). On the other hand, the use of blended methodologies with a strong tutorial action to keep contact between professors and students allow a very relevant increasing in the academic results (SSR). From the comparison of experiences, it is also clear that an innovative evaluation mechanism and a strong tutorial action allow a better learning than any other approach. This idea is also supported by the fact that all subject with more than one open channel for tutorial action (SD and SSR) present a relevant improvement in the academic results compared to approaches where only synchronous tutorial (the most traditional mechanism) is allowed.

On the other hand, students' responses to the survey may also be compared. Fig. 2 shows the results of this survey, regarding the previously introduced research questions.

As can be seen, boxplots do not show almost any overlapping area. In that case, no statistical test is required to analyze the results, as the Mann-Whitney U test is only essential when overlapping areas do not allow a heuristic analysis.

From Fig. 2 it is clear that experiences where the number of classes was high and a strong tutorial action was also deployed, are greatly better valued by students than methodologies based on autonomous learning and a limited contact with professors (PHR), and even if the final academic results do not show this harmful effect. In question E#2 it seems experience in SSR is not valued, but from personal interviews we got some very relevant comments. Although students refer the evaluation was not similar to previous years, they mean it in a positive manner, as they feel it was much better and learning-focused than usual (as shows E#1). Although other key elements such as motivation or students' comfort were not measured in this study, there are relevant variables to consider; as although final academic results do not show any negative effect, the experience seemed to be harder for students if they do not maintain a fluent contact with professors (through classes, tutorial action, etc.).

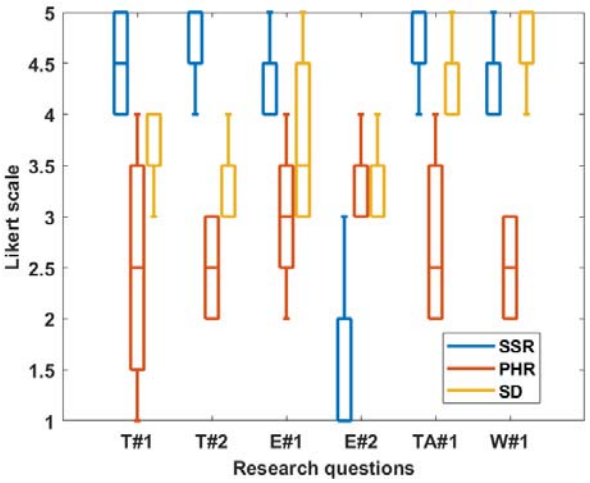

Fig. 2 Results of the survey: students' responses

Finally, in Table IX, we are comparing the workload of professors in the different subjects. As can be seen, as more tutorial channels are opened, the professors' workload suffers a very relevant and exponential increase, causing (as professors report) some punctual period of congestion and blocking. This variable is very important as, in long-term experiences, it may finally imply a relevant decreasing the whole education quality.

TABLE IX
PROFESSORS' WORKLOAD

		SSR		PHR		SD	
		2019	2020	2019	2020	2019	2020
SSR	2019	--	***	*	**	**	**
	2020	***	--	***	***	**	**
PHR	2019	*	***	--	NS	**	**
	2020	**	***	NS	--	**	**
SD	2019	**	**	**	**	--	NS
	2020	**	**	**	**	NS	--

NS not significant; * significant at $p < 0.05$; ** significant at $p < 0.005$; *** significant at $p < 0.001$

VI. CONCLUSION

In this paper, we are describing three educational experiences in two different Universities in Madrid, carried out during the COVID crisis (March – June 2020). On the one hand, Technical

University of Madrid, a public university with little experience in online education. On the other hand, Alfonso X el Sabio University, a private university with more than five years of experience in online teaching. Experiences ranged from innovative solution redesigned for the COVID era, to simple transfer of traditional methodologies and mechanisms to the virtual world. Results have showed the academic results of students, as well as their satisfaction is much greater when innovative methodologies are employed; however, the professor's workload exponentially increases in those cases. A more balanced approach is probably required in the future.

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