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STRENGTH OF MATERIALS DIGITAL SOLUTIONS

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Abstract: *Restrictive conditions on modern society were imposed to avoid congestion, partial or total lockdowns, during the SARS-CoV-2 pandemic. The downside, from the education system point of view, imposed the transfer of classes in an online environment. Thus, the impossibility of being present near industrial equipment slows the understanding of the physical and mechanical phenomena. This problem, whose solution had to come fast and from the digital environment, is addressed in this paper, by developing digital and physical systems that allows students to control an experimental stand from their devices. A questionnaire was applied to evaluate this solution; it was statistically analysed in SPSS using reliability analysis statistics and the resulting evaluation metrics are presented in this paper.*
Key words: *digital engagement, online laboratories, laboratory stand, real-time control, student opinion, statistical analysis.*

1. INTRODUCTION

The context of developing digital solution in the context of online communication is strongly related to the internet. The online environment offered us, the modern society, the possibility to send a substantial amount of information very fast; to communicate at the speed of light. This idea was first stated in 1962 by Joseph Carl Robnett Licklider, one of the first pioneers in this field, that theorized that to increase human thinking, we need the ability to communicate over a network, thus all of us being interconnected [1]. The rapidly arousing interest in communicating thru the internet made it a general-purpose technology [2-5]. The global coverage area is expanding at an unprecedented pace [6] thus, the internet speed and broadband are not an issue for most developed countries [7]. Therefore, theoretically, the education system worldwide could be transitioned from face-to-face to online classes, working in a risk-free environment [8-10].

Looking back at the pandemic lock-down severe issues emerged from face-to-face to online transition, as not all nations have the necessary infrastructure [11-18]. It is known that a large part of the existing learning system is based on the 19th-century factory model [19], and some methods of teaching are not updated in most countries; therefore, their digital counterpart emerged in the online environments as unprepared to sustain the complexity of online classes through the internet coverage area, shortage of physical devices (tablets, laptops, or personal computers), teachers and professors outdated by this technology, students' passive participation at classes, thus a lack of direct professor-student control and interaction [14-18].

As shown in this paper, the lack of physical interaction between students, teachers and industrial equipment can be solved by implementing a digital solution to laboratory stands. However, by giving up direct contact with materials, students cannot experience how parts are machined or tested (stretch, bend or fractured). An enhanced interaction leads to an easy understanding and long-term memorization [20]. As part of the Engineering Department, our students are oriented to a logical-mathematical and visual-spatial type of intelligence [21]. For us, a primary concern was to provide complete information in such a way so that students could understand it with ease. A digital system was therefore developed to convey the information

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as completely as possible and to be easily understood. This paper aims to present the methodology of the system, how it was implemented in the Strength of Materials laboratories, how it can be used when returning to face-to-face classes and the analysis of a 25-question survey concerning the student's opinion on this solution.

2. METHODOLOGY

2.1 General methodology

Working in a digital environment seems convenient as numerous digital materials are available online for free or with low price subscriptions. Popular websites, such as YouTube.com, Vimeo.com, DailyMotion.com or even Facebook.com, offer a wide variety of video content related to physical phenomena, on how a product work and fails tests. As ideal as it sounds, this information is not always fully verified, correct, or even accurate and, in most cases, needs to be translated from English. Young students can misinterpret the information; therefore, we consider that it is essential that they receive filtered in-formation and that we have to offer them the possibility of learning with confidence how physical phenomena occur from a technical point of view. Thus, experimental stands are required. The Strength of Materials classes represents a fundamental discipline for every engineering student, as they concern how materials react to external mechanical forces and what factors lead to deformation, cracking, or fracture [22]. Therefore, materials must be analysed through length, cross-section shape, area and orientation, mechanical properties, fixture type and applied loads. To understand the full extent of material behaviour, laboratories for tensile strength, beam bending, elastic constants, torsion, bucking, and material hardness are conducted.

The proposed digital solution was implemented in the papers of beam-bending, torsion, and bucking laboratories. The laboratory stand was designed and tested using 3D Computer Aided Design (CAD) and Computer Aided Engineering (CAE) software. The frame of the experimental stand needed to be lightweight, strong, and rigid; the lack of component stocks in stores, during the lock-down, imposed manufacturing of custom, in-house-made parts. The stand had to be controlled from both mobile and P.C. platforms. Overall, an optimal design indicated a modular laboratory stand, assembled from a 20x20 mm extruded aluminium profile, interchangeable 3D printed parts, and easy-to-acquire Arduino Mega 2560 microcontrollers, sensors, and drive system. This all-in-one framework is controlled by a graphical user interface (G.U.I.) that intends to be easy to use. The software for the microcontroller was written in C++, and the G.U.I were written in Java.

2.2 Experimental stand methodology

The experimental stand was constructed from 20x20 mm extruded aluminium alloy with T-slot openings on each side. The overall size of the stand is 1000x240x340 mm, considering restrictions of the 3D printer printing space, as each part was designed as a one-piece; thus, for a high-quality print, a 180x180 mm space was used. On this main assembly, different parts can be mounted so that three configurations can be obtained, consisting of the laboratory papers. The main challenge is to design the drive system so that it remains fixed in place in any configuration while it can allow transferring motion as translation or rotation. The versatility of 3D printing offered the possibility of making parts quickly (for example: worm gear and rack-pinion). In these three configurations, the force acting upon the testing material was measured using a 10 kg loading cell; linear and angular displacement was measured using ultrasonic and gyroscope sensors.

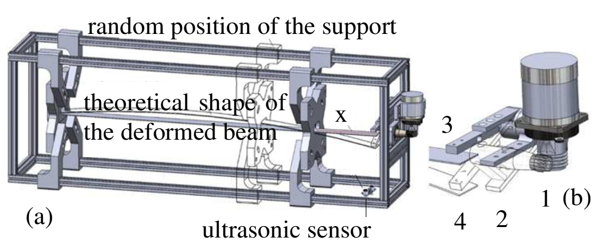


Fig. 1. Experimental stand configured for beam bending (a) indicating the ultrasonic sensor, fixture positions and beam undeformed and deformed shape, drive system assembly for worm gear mechanism (b) applying load to the beam (1 – worm gear, 2 – pivot connector, 3 – load cell, 4 – rectangular beam)

For students to understand the behaviour of various cross-section beams under different loading and support conditions, the experimental stand is arranged in the beam bending configuration, highlighted in Figure 1.

The bending configuration allows more cases to be studied, such as the beam can be fixed at one end and free at the other, fixed at one end with a pin/roller intermediary support, or double pin/roller fixture with the load acting on one end, double intermediary pin/roller fixture with two loads action on each end or double pin/roller fixture on each end with the load acting in between the supports. Students can calculate the beam dis-placement, bending radius, theoretical modulus of elasticity (Young's modulus) and percentual error between calculated and measured values.

The second configuration allows measuring a rod's specific torsion angle and torque. As noted in Figure 2, the beam is fixed at one end, and torque is applied on the other. The rod deforms by a certain angle, considering to the applied torque, beam material and cross-section. In this case, the load cell is fully fixed, and the gear system acts upon it, thus measuring the force needed to rotate the beam a certain amount. The students have to compare this value to the calculated torsion angle, torque, and polar moment of inertia.

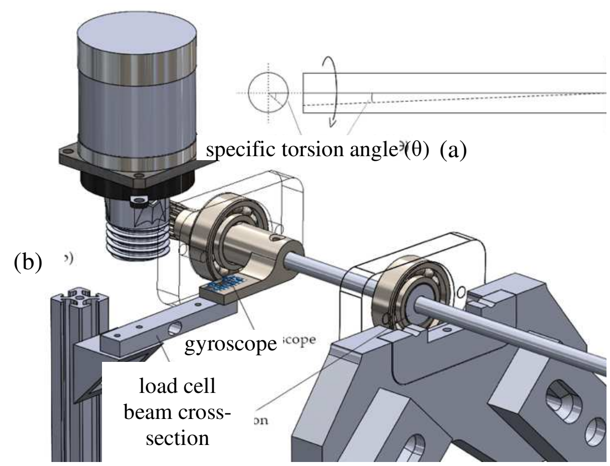


Fig. 2. Experimental stand configured for beam torsion, indicating the working principle (a) and how torsion is applied (b) thru the drive system assembly how the torque and specific torsion angle are measured

Buckling occurs as a beam is deformed under compression by an axial force (critical buckling load). In this case, students need to understand the mechanism of this effect when different support conditions are used and how intermediary supports stiffen a structure. In Figure 3, the bucking configuration of the experimental stand is shown, along with a detailed view of the rack–pinion drive system and load cell location. Calculating the critical buckling force consists in determining parameters such as the fundamental bucking mode (equal to the number of sideways supports + 1), Young's modulus, cross-section minimum axial moment of inertia, and buckling length by calculating and recognizing the type of fixtures. The buckling fixture assembly configurations for fixed and mobile support allows for a fully fixed beam on one side and articulated at the other, a double articulated beam and a fully fixed beam. Changing the position of the fixtures buckling main system allows the different fundamental buckling modes to be tested.

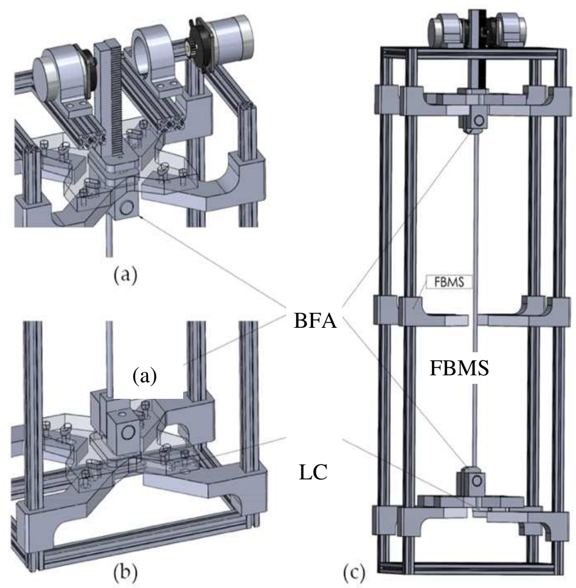


Fig. 3. Experimental stand configured for buckling; drive system assembly with rack – pinion mechanism break view (a), B.F.A. - buckling fixture assembly (b), FBMS - fixtures buckling main system (c) allow multiple buckling modes, and L.C. - load cell assembly

2.3 Student – experimental stand interaction

The students interact with the experimental stand through custom-developed applications. Two of them allow the control of the stand, one from within the Microsoft Teams platform, using the Share Screen option, and another from within an Android application for face-to-face classes.

Students can see the deformation of the beam in real-time; in each of the cases presented, a camera view was embedded. The layout of the applications allows direct access to the drive system by controlling the direction of rotation and speed of the stepper motors. The sensor measurements are read by the microcontroller and sent to the user interface as real-time data. The live video feed is displayed on each application.

The Microsoft Teams Application Share Screen option allows the professor to grant access and control to any student to their desktop. Therefore, they can control the experimental stand from their devices. An Android application was developed for face-to-face classes with the same functions. As it can be noted from Figures 4 and 5, the G.U.I. is composed of layouts indicating the message title bar, drive system control buttons, a webcam live feed viewer, and measured values scroll view.

Fig. 4. Graphical user interface, used to control the experimental stand by students in online classes, managed via the Microsoft Teams Share Screen platform

Returning to face-to-face classes has been a gradual process, and hybrid scenarios were adopted as the students raise many concerns. Some of them were worried about the direct or indirect contact with other colleagues, travelling to the University by public transportation, recreation breaks and even where and how they eat, despite the numerous actions that were taken to assure a safe environment. As an extra safety measure, the Android application was developed so that students could interact with the experimental stand from a safe distance without touching it, avoiding creating a crowd near the stand.

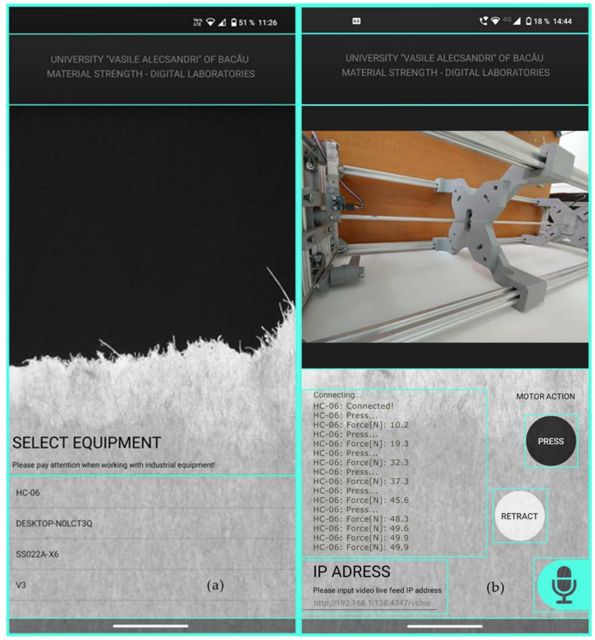


Fig. 5. Android application was used to control the experimental stand by students in face-to-face classes

The outcome of the solution can be seen in Figure 6. In this buckling configuration, the beam is deformed according to the type of fixture at each end. In this case, the students can observe how the system evolves by analysing the force acting upon the beam, its deformed shape, and the angle of rotation of each support; the actions and readings are done in real-time so that the students can visualize step-by-step the mechanism of deformation.

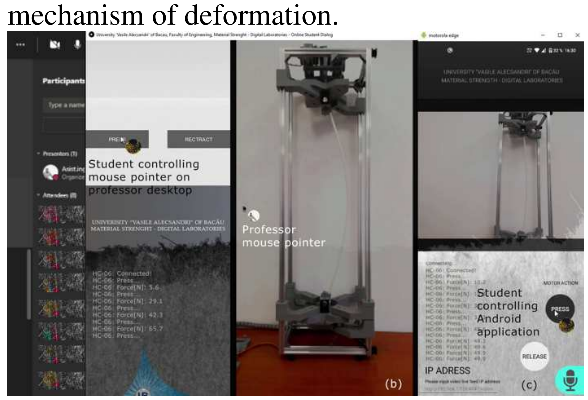


Fig. 6. Student controlling, via the Microsoft Teams Screen Share platform, the experimental stand in buckling configuration

2.4 Questioner and statistical validation methodology

To test the efficiency of the methods used and improve the application in laboratory works, we also used a quantitative tool, namely an online questionnaire applied to a number of 140 students using the Microsoft Forms platform. The design of the questionnaire, presented in Table 1, included a number of 25 closed questions that had the following objectives:

- O1: to probe the efficiency of the classical teaching methods compared to the digital ones during the pandemic.
- O2: to analyse the applicability of these methods in the laboratories in the field of Engineering.
- O3: to interpret the feedback obtained from students to improve these digital methods.
- O4: to explore the solution's applicability in other areas or in the context of face-to-face teaching.

Table 1

Applied questioner sorted by objective and question number.

O 1-4	Q. no.	Question
1	1	How effective during the pandemic are the classical methods of teaching laboratory work (live streaming or recording of stands during work)?
	3	Do you think the digital method of controlling the experimental stands is suitable for understanding the mechanical phenomena?
	23	Do you think this technique is helpful in learning?
2	2	Do you appreciate the laboratory support clearly conveyed in the practical work for Strength of Materials?
	5	Are the testing methods adequate for materials?
	6	Does the control mode (computer software application) provide the necessary control functions and answers/measurements?
	7	Is the android smartphone application a necessary tool in the materials strength laboratories?
	11	Is such a control system helpful in exemplifying the problems encountered at the Strength of Materials seminar?
	14	Is the image quality (resolution) adequate for understanding the mechanical phenomena?
	18	Do you consider the rigidity of the experimental stand sufficient to carry out the laboratory work within the Strength of Materials discipline?
	19	Is it necessary to explain in detail the mode of operation of the sensors and the control mode of the experimental stand?
	25	Are the materials and sections we used enough to provide complete explanations of the mechanical phenomena analysed?
3	4	Does viewing the stands in real-time improve the way of interpreting the mechanical phenomena?
	8	Does gradual control of the application of loads/forces help you to understand the mechanical phenomena quickly?
	9	Do you think it is necessary to improve the experimental stands?
	10	Is the feedback provided by this digital control system helpful in strengthening/consolidating the theoretical notions acquired in the course/seminar?
	13	Do you consider interpreting the results appropriately, especially for the online environment?
	16	Do you consider that the level of understanding has been improved by adopting these digital control methods?
	20	Was the effect of the forces/loads easily noticed?
	21	Is the effort made to understand the analysed mechanical phenomena increased?
	22	Do you think that such experimental stands should be implemented for all laboratory work within the discipline of materials resistance?
	24	Did you have the opportunity to express yourself freely through the remote control of the experimental stand?
4	12	Is a similar experimental digital stand control system necessary with the return to physical format?
	15	Do you want similar systems to be implemented in other laboratories of other disciplines?
	17	Does the production of plastic parts (3D printing) open new horizons for you?

To discuss and draw conclusions from the data obtained, we must ensure they are relevant; thus, a statistical analysis is required. The questionnaire results were validated using the SPSS software, v28.0.1 (I.B.M., Armonk, NY, U.S.A.), using the reliability analysis [23-25]. To be able to perform this analysis, the answers to each question had to be coded into numerical values (for example: Necessary in a very large proportion - 1, Quite necessary - 2, Necessary in a very small proportion - 3, It is possible without it – 4 and I cannot appreciate it - 5). Also, the measurement level was set to Ordinal (for questions: 1, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 16, 18, 19, 20, 22, 23, 25 and age category) and Nominal (for questions: 2, 3, 9, 15, 17, 21, 24, environmental belongings and gender) as indicated by [26], [27].

The reliability analysis statistics results were set to summarize Cronbach's Alpha coefficient and Analysis of Variance (ANOVA) with

Tukey's test for non-additivity. In this case, the emphasis is on Cronbach's Alpha coefficient and model significance (p-value). Furthermore, a frequency analysis was performed in SPSS; this type of analysis is helpful as the data is divided into categories indicating how many subjects answered each item of each question, providing results in both numerical and percentage format; the results are indicated in the description of the graph, presented in the results and discussions section.

3. RESULTS

The reliability analysis indicates that all input items are valid for this test, and therefore it uses all of them (N = 140, students), as indicated in Table 2. The Cronbach's Alpha is a reliability estimator, with values ranging from 0 to 1, that looks for external influence factors and, depending on the calculated value, indicates if the items have relatively high internal consistency [27]. General values for this coefficient are between 0.6 and 0.7 and indicate an acceptable level of reliability. Values of alpha lower than 0.6 indicate that there are not enough questions, while values higher than 0.95 are not acceptable, as they may indicate redundancy in the scale items, as indicated in [28-30]. Therefore, considering these intervals, the indicated range is between 0.8 and 0.95 [28]. Considering the Cronbach's Alpha coefficient of 0.873 (Table 2), obtained for all questions (N of items = 28, questions), it can be stated that the items involved measure the same concept; thus, it is reliable.

Table 2

Case processing summary and reliability statistics results.

Case processing summary			**Reliability statistics**		
Cases	N	%	Cronbach's Alpha coefficient	Cronbach's Alpha Based on Standardized Items	N of items
Valid	140	100	0.873	0.889	28
Excluded	0	0			
Total	140	100			

The ANOVA with Tukey's test for non-additivity indicates if any significant interaction between dependent variables exists [31]; the evaluation is performed by ana-lysing the p-value; if the value is lower than 0.05, the results are considered significant [32]; therefore, the interaction between dependent variables is present. As indicated in Table 3, evaluating the overall p-value, which is lower than 0.001, highlights significant interactions between items involving different magnitudes. Moreover, as can be noted in Table 4, the p-value of each question is below 0.05. Considering this, the model is statistically significant, correlation between items exist so they can be analysed and discussed.

Table 3

Overall ANOVA with Tukey's Test for non-additivity analysis results.

			Sum of Squares	**df**	**Mean Square**	**F**	**Significance (p-value)**
Between people			393.43	139	2.83		
Within	Between Items		181.80	27	6.73	448.22	< 0.001
	Residual	Non-additivity	16.75	1	16754	47.09	< 0.001
		Balance	1334.68	3752	0.35		
		Total	1351.44	3753	0.36		
	Total		1533.25	3780	0.40		
		Total	1926.68	3919	0.49		

Table 4

ANOVA p-value result for each question, related to environmental belongings, gender and age category.

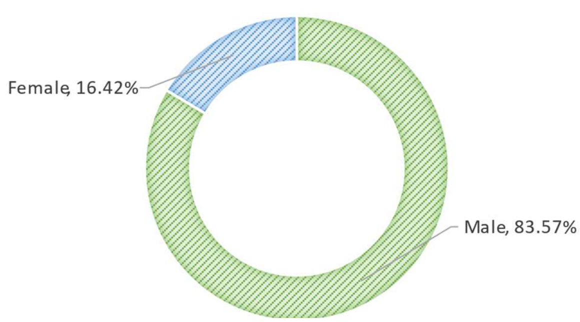
	Q 1	**Q 2**	**Q 3**	**Q 4**	**Q 5**	**Q 6**	**Q 7**	**Q 8**	**Q 9**	**Q 10**	**Q 11**	**Q 12**	**Q 13**
Mean Square	0.449	0.034	0.421	0.23	0.235	0.405	0.428	0.314	0.481	0.352	0.294	0.595	0.286
df	138												
F	6.682	5.308	16.312	22.684	17.508	25.499	22.248	36.346	7.858	13.208	87.465	28.23	3.907
p-value	0.011	0.023	<.001	<.001	<.001	<.001	<.001	<.001	0.006	<.001	<.001	<.001	0.05

	Q 14	**Q 15**	**Q 16**	**Q 17**	**Q 18**	**Q 19**	**Q 20**	**Q 21**	**Q 22**	**Q 23**	**Q 24**	**Q 25**	
Mean Square	0.343	0.509	0.338	0.044	0.438	0.461	0.236	0.352	0.25	0.194	0.323	0.387	
df	138												
F	30.835	40.187	28.931	13.151	24.196	14.876	39.264	24.824	54.134	72.995	24.784	24.583	
p-value	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	

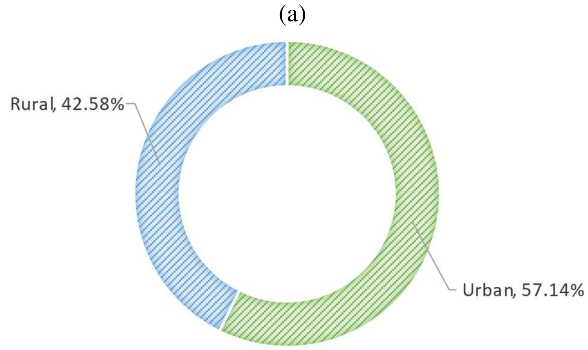
4. DISCUSSIONS

4.1 Subjects distributed by gender, environment belonging and age

The 140 subjects came from 5 specializations which experienced during the pandemic the use of digital methods in laboratories for Strength of Materials as a university subject. 57.14% come from urban areas and 42.58% from rural areas, respectively 117 boys and 13 girls, as indicated in the graphs from Figures 7a and b. The good representation of those from rural areas helps us to investigate whether they encounter difficulties in using digital methods and their usefulness. The segmentation by gender categories is justified by the field of study in which it was applied, but it shows us that the female segment can quickly adapt to the new methods applicable in laboratories. This fact was corroborated, as indicated in Figure 7c, with the representation by age categories, respectively: between 20-25 years - 81; between 25-30 years - 14; between 30-35 years- 14; between 35-40 years - 13; over 40 years -18 to see if the appeal of these methods is more significant among young people or if the online environment has developed and diversified digital skills for all these selected segments.



(a)



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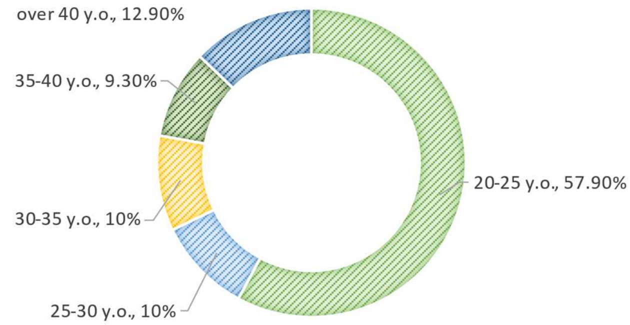

(c)

Fig. 7. Classification of subjects according to (a) gender (23 Female and 117 Male); (b) environment belonging (80 Urban and 60 Rural), and (c) age (81 between 20-25 years old, 14 between 25-30 years old, 14 between 30-35 years old, 13 between 35-40 years old, 18 over 40 years old)

4.2 Objective 1. Probe the efficiency of the classical teaching methods compared to the digital ones during the pandemic

The first objective of the questionnaire was to analyse the efficiency of the classical teaching methods compared to the digital ones during the pandemic. In this regard, two "ice-breaking" questions were designed to introduce respondents to the research topic and a control question to test the fidelity and accuracy of the answers. The first question How effective during the pandemic are the classical methods of teaching laboratory work (live streaming or recording of stands during work)? On the one hand, it is aimed at differentiating between the classical and digital methods to make respondents aware of this differentiation, and on the other hand, at their efficiency in online education. 41.42% consider that they are very efficient, 47.14% quite efficient, 10.71% have low efficiency, and 0.71% are no longer up to date. This fact shows us that there is a need to improve or duplicate classical methods with modern means and tools adaptable to the digitization of education.

Question no. 3 Do you think the digital method of controlling the experimental stands is suitable for understanding the mechanical phenomena? It is aimed at the method efficiency and the manner it is received by the subjects tested in laboratories. The answers were over 90% in favour, which shows that the subjects were delighted with this new approach, while 9% gave unfavourable answers, which were also related to the technical difficulties they encountered. This extremely favourable reception demonstrates, on the one hand, the exploration of a new approach applicable in laboratories in the context of the pandemic to maintain a certain degree of interactivity, as well as the appeal of a new method which manages to develop digital and professional skills alike.

Question no. 23, placed towards the end of the questionnaire, aimed to verify the students' honesty towards the digital methods after going through a reasonably large number of questions in which the other three objectives of the research were surveyed. Do you think this technique is helpful in learning? The data collection results showed that the subjects' answers were maintained, compared to those received to question no. 3 of the questionnaire, with a slight increase of 7 % in the assessment of the applied methods: 70% very useful; 27.85% quite useful; 1.42% not very useful and only 0.71% cannot appreciate. On the one hand, we consider that the 3 questions managed to make students aware of the importance of using the digital methods in online laboratories and the beneficial results that can be obtained by their complementary application with the classical methods.

4.3 Objective 2. Analyse the applicability of these methods in the laboratories in the field of Engineering

The second main objective of our research was to analyse these methods' applicability within engineering laboratories. For this purpose, a series of 9 questions addressed to students monitored the characteristics of the methods applied in the laboratories in the field of Engineering to the Strength of Materials discipline: clarity, exemplification, image quality, their adaptation to the specifics of the discipline, how to control the stand, stiffness, explanation sensors. All these elements had the following role: correlating the efficiency of applying digital methods to the discipline's specifics and the laboratories' technical conditions. Question with no. 2 Do you appreciate the laboratory support clearly conveyed in the practical work for Strength of Materials? Accounted for 96.42% are favourable responses from participants, while only 3.57% felt they did not clearly understand the laboratory support. This fact proves that the methods were well received, reaching the objective of going through the laboratory support as it was done in face-to-face teaching using the classical methods. Question no. 5 Are the testing methods adequate for materials? gathered a number of 90.71% favourable answers, 2.85% negative answers, and 6.42 of the respondents do not know how to evaluate. We can note that the 2 questions managed to accumulate over 90% of the answers as having a positive impact among the audience on the application and adaptation of methods to the content and specificity of laboratory hours.

Question no. 6 Does the control mode (computer software application) provide the necessary control functions and answers/ measurements? Received favourable answers in a proportion of over 95%, while 3.57% of the subjects cannot appreciate and only 0.71% agree to a small extent.

The same trend is maintained in the case of the following two questions, and respectively, question no. 11 Is such a control system helpful in exemplifying the problems encountered at the Strength of Materials seminar? Furthermore, question no. 14 Is the image quality (resolution) adequate for understanding the mechanical phenomena? with over 90% positive reactions that reinforce both the application and the visual component.

The following 2 questions in this series, placed one after the other to maintain the subjects' attention regarding the evaluation capacity of the experimental stand, the operation of the experimental stand and the operation of the sensors, kept a high percentage of favourable answers of over 90%, which shows that respondents maintain their appreciation of how the digital methods have been applied in laboratories.

Question no. 19. Is it necessary to explain in detail the mode of operation of the sensors and the control mode of the experimental stand? Certifies that these methods are functional but require detailed explanations and accurate indications regarding the operation of the sensors to be understood and applied by student.

The last question in this set that addressed the second objective placed as the last in the questionnaire summarized the general impression left by the subjects of the digital methods applied in the laboratories of Strength of Materials. Question no. 15 Are the materials and sections we used enough to provide complete explanations of the mechanical phenomena analysed? Maintained a 60% favourable response rate, 36.42%, considering that they are sufficient to some extent, thus opening new possibilities for improvement or correlation with other complementary methods.

4.4 Objective 3. Interpret the feedback obtained from students to improve these digital methods

The third objective was to obtain feedback from students and interpret it to improve these digital methods. Through a series of 10 questions, the questionnaire surveyed the changes that should be made to facilitate understanding the content, the technical difficulties, and the relationship between the digital methods and the online environment. To question no. 4 Does viewing the stands in real-time improve the way of interpreting the mechanical phenomena? A percentage of 97% consider there are significant or enough improvements, compared to 2.14% who answered that the improvements are minor. These figures further demonstrate the high percentage of subjects who appreciated the application of digital methods in laboratories.

Question no. 9 Do you think it is necessary to improve the experimental stands? It was conceived as being correlated with question no. 18 to see if the answers hold. If in question no. 9, 70.7% consider that the stands should be improved, to question no. 18, which thus becomes a control question for the one from no. 9, 62.14% consider that the rigidity of the stand is sufficient to a large extent.

A series of 3 questions summarized the specific issues applied in the laboratory: Was the effect of the forces/loads easily noticed? Is the effort made to understand the analysed mechanical phenomena increased? Did you have the opportunity to express yourself freely through the remote control of the experimental stand? The subjects answered in a proportion of 72.14% that the effect produced was observed to a large extent, 69.28% that the effort was of increased intensity, and 57.14% that they were able to express themselves freely through the remote control of the experimental stand.

To the question no. 22 Do you think that such experimental stands should be implemented for all laboratory work within the discipline of materials resistance? The students' feedback was a positive one towards this experiment carried out in the laboratory. Data indicates that a percentage of 31.42% considers that it can be applied only for a part of the work must be correlated with the answers to question no. 15, in which 17.85% consider that it can be applied only depending on the specifics of the discipline.

Following the application of the digital methods in the laboratory, we were interested to see if the feedback provided by this digital control system helps strengthen/consolidate the theoretical notions acquired in the course/seminar. Beyond the specific questions on certain components or characteristics, question 10 aimed at students' general impression of the relationship between digital methods and the transmission of theoretical knowledge.

Another relevant aspect was the correlation of the application of the digital methods, especially in the context of online teaching or their extension to both online and face-to-face education: Do you consider interpreting the results appropriately, especially for the online environment? 60.71% of respondents considered that they should be applied regardless of the form of teaching due to the results they generate.

Question 16: Do you consider that the level of understanding has been improved by adopting these digital control methods? The interpretation gives us answers that can be correlated with questions 10 and 23, confirming the accuracy of the answers received.

4.5 Objective 3. Interpret the feedback obtained from students to improve these digital methods

The latter objective explored the applicability of methods in other areas or the context of face-to-face teaching. To question no. 12, Is a similar experimental digital stand control system necessary with the return to physical format? 85% of respondents consider it necessary, compared to 8.57% who answered that it is necessary for a very small pro-portion and 2.85 that it is possible without it. This fact shows us that once the students have become familiar with these methods and have seen the results, they want to apply them in face-to-face laboratories, not only in those conducted online.

Question no. 15 aimed at the sustainability of these methods and their implementation in other laboratories for other disciplines. The figures show positive feedback on their expansion to other disciplines, compared to the relatively small percentage of only 3.57% who reject this perspective. 17.85% of students considered that this fact must be weighed according to the specifics of the discipline to see if some areas/disciplines can be better received by using the digital methods and others which must use the classic ones.

The interpretation of the responses is to the last question of this set, no. 17 Does the production of plastic parts (3D printing) open new horizons for you? 95% confirmed that added value and new perspectives could contribute to the diversification of laboratory topics.

5. CONCLUSIONS

The online environment leads us to know the student from another perspective. The experimental stand allowed us to adapt to the student's needs and allowed them to understand better what we wanted to transmit, considering that this was made in an online environment. Furthermore, this solution can be implemented on any platform that allows screen sharing, such as Zoom, Cisco Webex Meetings, GoToMeeting, Discord, Google Hangouts, Any Meeting or even TeamViewer. The main idea that drives this project is to create a system that can allow us, as teachers, to deliver the information so that it is simple to understand and to allow the students to recreate what-if scenarios to clarify their thoughts.
All in all, the 25 questions in the questionnaire managed to answer the four objectives. They were all validated by the subjects' answers. The high positive percentages recorded have shown that the digital methods were quickly implemented in laboratories, both thematically and technically. The processing of the answers has also revealed several improvements which should be made to the digital control system, as well as the possibility of extending it to other laboratories or disciplines, online or face-to-face education. The evaluation of the questionnaire using reliability analysis statistics, such as Cronbach's Alpha coefficient and Analysis of Variance (ANOVA) with Tukey's test for non-additivity, indicated that the results are significant at the model and individual level. Furthermore, the results indicate that the items involved converge to the same output.

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SOLUȚII DIGITALE PENTRU REZISTENȚA MATERIALELOR

Rezumat: În timpul pandemiei SARS-CoV-2 au fost impuse condiții restrictive asupra societății moderne pentru a evita aglomerația, blocările parțiale sau totale. Dezavantajul, din punct de vedere al sistemului de învățământ, a reprezentat transferul de cursuri într-un mediu online. Astfel, imposibilitatea de a fi prezent în apropierea echipamentelor industriale a făcut dificil procesul de înțelegerea a fenomenelor fizice și mecanice. Această problemă, a cărei soluție trebuia să vină rapid și din mediul digital, este abordată în lucrarea prezentă, prin dezvoltarea unor sisteme digitale și fizice ce le permit studenților să controleze un stand experimental de pe dispozitivele lor mobile. A fost aplicat un chestionar pentru evaluarea acestei soluții; acesta a fost analizat statistic în SPSS folosind statistici de analiză a fiabilității, iar evaluarea rezultatelor este prezentată în această lucrare.

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