EAI Endorsed Transactions
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Virtual Learning Approach Toward Introductory Biological Engineering Course in Uruguay During COVID-19

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Abstract

INTRODUCTION: Global education has seen a paradigm shift in the recent years; especially in life sciences, specializations have started sharing common space in applied research and development. Extending the transdisciplinary approach to undergraduate programs, a case study on the introductory course of Biological Engineering program at University of the Republic *(Universidad de la República)* Uruguay is presented.
OBJECTIVES: The COVID-19 pandemic has led to shifting the biological engineering course to virtual modality, changing the pedagogical dynamics. This study aims at analyzing the adaptation to the new model of virtual learning.
METHODS: Different course metrics over time has been analyzed along with surveys on students and professors of the course.
RESULTS: Despite several new challenges posed by the virtual modality, the overall student-performance didn't decline.
CONCLUSION: The biological engineering course presents interesting contents especially in its course design and student engagements, remodeled especially during its virtual mode.

Keywords: Education, Creativity, Innovation, Biological engineering, Peer-learning, COVID-19, Pandemic, Virtual Learning.

Received on 10 September 2020, accepted on 16 October 2020, published on 26 October 2020

doi: 10.4108/eai.26-10-2020.166769

1. Introduction

The status of education has always been one of the primary factors of development in defining academic capital, human resource and vision of development [1,12]. In the digital era, one of the crucial areas which needs to embrace newer technologies and cutting-edge paradigms is education. During the transition from high school to university-level education in Science, Technology, Engineering, and Mathematics (STEM), it has been observed that a significant number of students lack clarity regarding the scope and applications of the career or study program they choose [11], which often reduces their commitment to their chosen career. Especially in the domain of life sciences, the uncertainty among the students especially with respect to the future scope of their career is caused by several factors, including inadequate exposure to the state-of-the-art in the field, or limited access to professional development in parallel to the university courses, or unsatisfactory communication with referents and leaders in the field. These issues, observed over a span of several years in the Department of Biological Engineering of University of the Republic *(Universidad de la República)*, Uruguay, led to the development of a new course from the ground up, totally redefining the approach toward the introduction of course topics as well as the teaching and learning paradigms. The objective of cross-fertilization between creativity and interoperability in a transdisciplinary environment was central to this, fusing

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the domains of engineering and life sciences and leading toward an enhanced learning experience for the students, providing them with state-of-the-art transferable skills to enable them to excel in a career in life sciences [13]. Given the importance and global demand for skilled professionals in the life sciences, it has been essential for the graduates to possess the necessary skills even beyond the usual curriculum of biology, which would facilitate them to continue their career in a concrete way. Considering a global scenario, a lot of real-world problems in life sciences need a combined multidisciplinary collaboration to resolve them, reducing the barriers between engineering and basic and applied sciences. It also aimed to reinforce the idea of collaboration toward problem-solving for the students, even within a classroom-environment, which could be utilized in future scenarios.

Due to the COVID-19 pandemic, the university changed the format of all its courses in the Department of Biological Engineering and adopted virtual learning throughout the first and second semesters of the year. The introductory course to the biological engineering undergraduate career, 'Workshop of Biological Engineering - 1 *(Taller de Ingeniería Biológica - 1)*', was the most critical course in this respect. This course has the highest number of students compared to any other courses in the department and poses a crucial significance for the first-year students in giving a holistic view of the entire biological engineering program. The adaptation to virtual learning for this course involved a series of pedagogical changes, including course design and teaching methods, which had a diverse impact on the students and the professors. This study sheds light on the evolution of the course since its inception and analyzes the impact and new dynamics led by the change to virtual learning.

2. Analysis of the key issues in learning paradigms

The understanding of the existing issues in the field of biological engineering in the university spanned over several years, and one of the key aspects was the teaching and learning methodology. After analyzing several undergraduate courses over a period of time and incorporating the students' perspective, it was evident that the usual teaching methodology was obsolete in the face of cultural and technological changes. In a time of global demand for transferable skills, it was observed that the majority of the students lacked the quintessential skills for their future professional activities even after successful completion of their courses [2]. Moreover, the focus of the courses was not toward the enhancement of the thinking process and innovation of the students but was centralized on gathering the knowledge to pass the course. It generated a concurrent void in the thinking-element of the students in the long run, which contributed to a lack of motivation and disillusion about their career at a later stage. Also it has been observed that most of the students who joined the university after their high school experienced a substantial leap with respect to the learning paradigms, in addition to the level of difficulty of the courses or its contents [10]. This shift often impacted the students negatively, since most of the courses in biological engineering lacked an effort to bridge the gap or make the shift gradual and smooth for the students.

Another key area related to this discussion is the subject domain of the courses students usually take during their undergraduate studies. Especially in this case, due to the choice-based credit system, several courses were isolated and disconnected from each other, and students have been facing difficulties in connecting the dots and finding the link between these courses related to their program. Despite a significant part of the syllabuses being quite relatable to each other, the approach toward implementation and the gap between the theoretical and practical aspects of the courses affected the students adversely, making it difficult for them to work in interdisciplinary fields or even to possess the necessary abilities to solve real-world problems in the field. This clearly indicated that the learning and evaluation paradigms were not helping the students to attain useful skills in the long run.

In spite of the presence of several initiatives to address these issues at the regional level of South America, for example, in Argentina [3,11] and Uruguay [4-6], most of the approaches didn't focus specifically on bridging the gap between the academic domain and problem-solving visions in real-world scenarios. With the intention of resolving the issues which the students have primarily been facing, especially in the undergraduate level of biological engineering in the University, the task of designing a new course was undertaken. In this approach, the primary focus was on the course contents, teaching and learning paradigms and its global outreach to the state-of-the-art. Also, the intention was to facilitate the students in independent thinking and problem solving in a wider scenario, after obtaining the necessary skills during the course. With this motivation, the idea was to design the course from its base instead of reengineering a previous course.

3. Course Design

Since the course was thought to be an introductory course in undergraduate biological engineering program, the initial approach to the course design was to blur the boundaries of science and engineering, to develop the course on a transdisciplinary foundation of life sciences. This also involved a change in the entire departmental approach of biological engineering, which merged the disciplines of health sciences, biology, and engineering. The objective was to enhance the scope of the course, so that the students obtain transferable skills enabling them to solve real-world problems in the future, or to continue their career in transdisciplinary areas as well.

In this respect, the new course was named "Biological Engineering Workshop - 1 *(Taller de Ingeniería Biológica*

- *1)*", in alignment with other three workshops included within the undergraduate career of Biological Engineering. This was designed under the new framework of the Biological Engineering program of the University of the Republic, Uruguay *(UdelaR)* in 2014 [7]. The new course (Workshop 1) was introduced in the first year of the program (Figure 1). During the entire undergraduate degree of biological engineering, courses on basic sciences and engineering fundamentals were planned mostly in the first two years, while the last two years were more dedicated to core concepts of life science and specialized topics. However, in a complementary approach, the workshops in the first and third year were focused on providing a wider transdisciplinary aspect of the field by discussing a fusion of several topics, whereas the workshops in second and fourth year focused on core topics within the course.

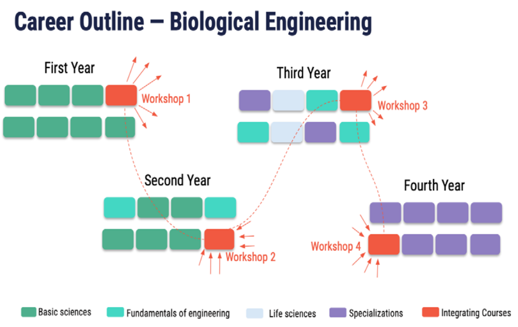


Figure 1. Outline of the undergraduate degree program of Biological Engineering in the University of the Republic *(Universidad de la República)*, Uruguay

The program primarily had a strong focus toward biological processes and life sciences. One of the expected goals from the students was that they possess suitable capabilities for working in multidisciplinary environments like the agri-food sector, biotechnology and bioinstrumentation sector, and even providing technological solutions to the healthcare sector. Based on the key motivations toward designing the new course, the following specific objectives were also put forward during the course-design (Table 1).

Table 1. Key objectives of the new course in Biological Engineering

Collaborative problem-solving	Motivating the students by providing opportunities for open problem-solving early in their course-career, to emphasize their creativity and teamwork
Engineering skills	Introducing students to engineering concepts, several tools and project methodologies
Science knowledge	Integrating a basic knowledge of biology, physics, electronics, mathematics, and computer science
Research and communication	Stimulating skills in research methodology and scientific communication

The course (Biological Engineering Workshop 1) is a one-semester course and is offered to all first-year students in the biological engineering program of the UdelaR. The weekly classes (4 hours each) span over a period of 10 weeks and consist of theory and practical sections, in addition to outside-the-class learning through directed readings, periodic practical assignments and a final project. With respect to the classes, the first class is designed meticulously, as it will be the first introduction for the first-year students to the career, along with a holistic view of life sciences and its allied and applied fields.

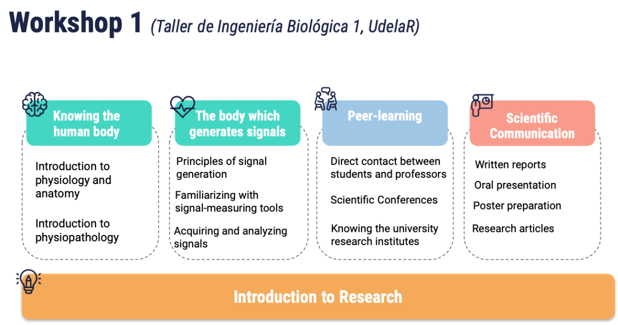


Figure 2. Modular vision of the new course (Biological Engineering Workshop 1) at the University of the Republic *(Universidad de la República)*, Uruguay

The key motivation behind designing the course in a specific modular manner (Figure 2) is to familiarize students with introductory concepts of the human body, along with several engineering tools and approaches to apply interactively.

The rest of the classes consist of four thematic modules where an introductory idea of human physiology like the muscular, cardiovascular, respiratory and neural aspects are introduced, followed by a special module integrating all those concepts and focusing on the applied aspects. In each of the areas, the general approach followed is the presentation of each area, explanation of the wide and convergent disciplines related to that area, current problems within that field relevant to the global scientific community, and introduction of engineering tools and their application in biological sciences and medicine. In each of these thematic modules (Figure 3), students are teamed into randomly chosen three-member groups to carry out practical laboratory activities in which biopotentials are measured, following which they present a written report. Throughout the entire course, special attention is taken in introducing the students to the state-of-the-art in the field. Every class consists of a specific segment where students are introduced to a trending topic in the field, mostly through online talks and papers, which later pose as a platform for open discussion between peers and the professors.

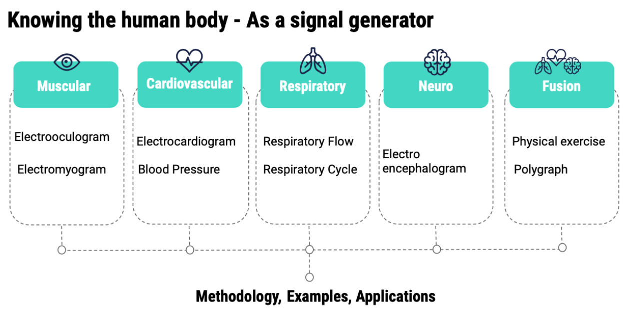


Figure 3. Thematic modules for theoretical and practical classes (Biological Engineering Workshop 1) at the University of the Republic *(Universidad de la República)*, Uruguay

The course was designed with the objective of twinning the theoretical and practical modules in an applied way, which will facilitate the students to immediately apply the concepts learnt into a real-world scenario. A major part of this involved non-invasive acquisition of signals from the human body and analyzing these thoroughly (Table 2).

Table 2. Key objectives of the new course in Biological Engineering

Muscular Physiology Module	Electromyogram	**Theory:** Fundamentals of anatomy of the muscular system, base of muscular contraction, action potential, electromyogram, applications, recording equipment, innovative projects in signal registration. **Practical:** Manipulation of instruments in the recording of the electromyography signal, recording of skeletal muscle tone at baseline levels of electrical activity, recording of maximum activation of muscle fibers in contraction, analysis of acquired data.
	Electrooculogram	**Theory:** Fundamentals of the anatomy of the eye, physiology of the eye movement, physical bases of the electrooculogram, recording of the electrooculogram, innovative projects in the registration and processing of the signal. **Practical:** Handling of instruments, tools and data, familiarization with the electrooculogram signal, analysis of the records, application of the register in the movement of objects
Cardiovascular Physiology module	Electrocardiogram	**Theory:** Fundamentals of heart anatomy, pulmonary and systemic circulation, cardionector system, action potential, cardiac cycle, electrocardiogram, innovative projects in signal acquisition. **Practical:** Familiarization with electrocardiogram measurement, recognition and manipulation of instruments, evaluation of electrical events of the heart and their association with mechanical events in the cardiac cycle, evaluation of changes in signal frequency under certain conditions
	Blood pressure	**Theory:** Relevance of the topic, fundamentals of blood vessel anatomy, arterial flow dynamics, systolic and diastolic blood pressure, regulation mechanisms, invasive and non-invasive

		measurement techniques, innovative projects in signal acquisition. **Practical:** Familiarization with different methods of measuring blood pressure and with the information provided by the data, taking measurements with different methodologies and tools, recording and comparing methodologies.
Respiratory Physiology module	Respiratory cycle	**Theory:** Fundamentals of respiratory system anatomy, pulmonary ventilation, ventilatory mechanics, static properties of the lung, gas exchange, breathing control, respiratory cycle measurement, innovations in measurement systems. **Practical:** Measurement and recording of pulmonary ventilation using pneumography and air and temperature transducer, relationship between theory and the phenomena observed in the signals.
	Respiratory flow	**Theory:** Fundamentals of respiratory physiology, air flow, resistance to air flow, breathing air flows, measurement of respiratory air flow, spirometry of flow, obstructive and restrictive pathologies of the respiratory system, calculation of flow and volume. **Practical:** Manipulation of instruments, tools and data analysis, familiarization with airflows in the airway, evaluation of volumes and capacities of the respiratory system
Neuro-Physiology module	Electroencephalogram	**Theory:** Fundamentals of anatomy of the nervous system, neurophysiological bases of the electroencephalogram, technological bases of electroencephalographic records, measurement recording devices. **Practical:** Data acquisition, derivations and assemblies, processing of recorded signals, pattern recognition in electroencephalogram signals
Integrating module	Physical exercise	**Theory:** General concepts, physiological responses and adaptations in physical exercise at the level of energy metabolism, cardiovascular system and ventilation, diffusion and transport of gases. **Practical:** Record and compare changes in lung flow, heart rate, and skin temperature before, during and after moderate exercise in different periods of duration.
	Polygraph	**Theory:** Physiological bases of the autonomic nervous system, physiological signals recorded in polygraph, evasion forms, false positive factors, signal recording equipment, application. **Practical:** Recording of pulmonary ventilation signals, electrocardiogram and electrodermal activity, observation and recording of changes in the signals associated with different types of stimuli, analysis

		of the three recorded signals.

The second part of the course consists of another integrating module which was designed with specific motives of enhancing the aspect of independent thinking of the students, in addition to utilizing their research skills. In this module, the students need to choose any topic in the wide domain of engineering in biology and medicine and perform a thorough study on that, including bibliographical study, seeing popular talks on the topics etc. At the end of the course, each student delivers a poster presentation based on their study. In this module, six classes are dedicated to guiding students to review scientific literature, scientific communications, presentations, and collaboration. Also, beyond the class-hours, special consultation classes are offered to the students, to keep a close follow-up during this process on one hand, and to strengthen their skills in scientific communication on the other hand.

Adaptation of the course structure to virtual learning

One of the primary challenges in adapting the course contents to the new paradigms of virtual learning was not just to ensure the adequate learning outcome, but also to make necessary modulation of the course contents to safeguard the interesting elements of it. Due to this, the theoretical part of the course has been reduced by decreasing the focus on physiological and anatomical modules, introducing more practical contents and increasing the importance of topics such as signal processing. Reducing the theoretical aspects of the course and focusing on more practical content included more emphasis on sensors, and relation of the practical modules with the theoretical contents discussed in the class.

This led to a thorough change in the order of the course contents, as in the new scenario, practical contents were introduced before the theoretical aspects. Also, the content of anatomical and physiological concepts had been reduced to accommodate more practical content on the topics of signal processing. It was aimed at keeping the focus on the students, to keep them at the participating end rather than just at the receiving-end of information. The practical contents were used to introduce the theoretical concepts, as the students take part in practical lessons like working on the signals measured from the body.

Another important part of the course content is the final module, including an independent study by each student, and a final poster presentation. In the new scenario, instead of keeping the module of bibliographic study at the end, it was introduced before the practical sessions, to introduce a parallel approach where the students were made familiar to the basics of literature review and scientific communications. Thus, instead of a completely independent study, the students performed guided study, where regular follow-up was performed by the professors in parallel to the course.

4. Teaching methodology and evaluation strategy — adaptation to virtual learning

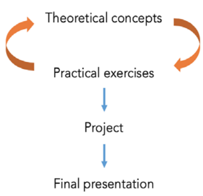
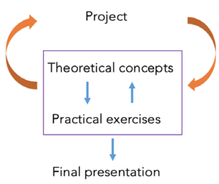
Designing the teaching methodology was crucial in this introductory course so that the student-student and student-teacher interactions stay fluid. The professors of this course were carefully chosen, mostly with the objective of reflecting their transdisciplinary work in the students. Another key objective of the teaching methodology was the active participation of the students during the class hours, and a complementary ubiquitous learning beyond class-hours. This was resolved by proffering one-to-one contact for every student with the professors, which continued in the last module as well. The students had the opportunity for direct contact and continuous conversation with professors from each area of specialization, to get active support and motivation during their final project.

The evaluation of the course was designed with several objectives. On one hand it was important to assess the students' knowledge about the specific topics taught during the course. On the other hand, it was crucial to analyze the students' participation during the course activities and their skills in independent thinking, problem solving in collaboration, and scientific communication and presentation. With these objectives, the evaluation of the course was designed in a two-fold procedure, where the first part is evaluated based on a written report by the students, and their performance during the classes and the practical lessons. The second part is evaluated based on an open-public oral presentation, where each student presents their findings of bibliographical study along with their own contributions through a poster, at the end of the course.

Adaptation to virtual learning involved several pedagogical changes in the course (Table 3), including the evaluation strategies. For example, 80% attendance was a compulsory criterion for this course. But in the new modality, it has been relaxed to 60%. Also, a comprehensive survey was performed to analyze the technical difficulties of the students. Students who did not have adequate technical support at home, like lack of stable internet connectivity and lack of devices to see and participate in the virtual classes, were considered and special measures were taken to make the virtual classes available to them. Especially for these students, all the classes were recorded and uploaded to the virtual classroom portal. The videos were compressed and uploaded in optimized quality as well, to assist the students with limited internet resources.

Interaction and student engagement stood as the key challenges in the new virtual modality. In the usual scenario, a thirty-minute ice-breaker quiz (using Kahoot) was performed before every class. The key objective was to facilitate a recapitulation of the previously discussed topics and keep the students engaged with the topic. However, in the new virtual scenario, synchronizing all the students was complicated due to technological disparities, causing delays in the interactions. Instead of a quiz, a thirty-minute pre-class Question-Answer (QA) session was conducted, which initiated group discussions between the students and professors. Though the new theoretical classes were more concise, a fluid student interaction was difficult to achieve in the virtual format. The evaluation strategies of the course were also changed in the virtual system. The students were provided with periodic tasks in groups which were monitored closely by each professor and were individually evaluated through periodic classwork and homework.

Table 3. Adaptation of the new teaching paradigms adapted to virtual learning

Course Feature	Usual classroom scenario	Virtual classroom scenario
Theoretical classes	2 hours	1 hour 30 minutes
Practical classes	1 hour 30 minutes	45 minutes
Pre-class interactive session	30 minutes ice-breaker quiz	30 minutes
Video of Class lectures	Not recorded	Group discussion and QA-session between students and professors
Course flow		
Follow-up of students	During/after every class (group)	Special tutoring to groups or one-to-one video meeting throughout the week

With the change to virtual learning, the final presentation of this course was shifted to virtual presentation, where the students present using ePosters and answer questions asked by their peers and the professors.

A key aspect that has changed completely in the virtual learning scenario is the follow-up with students. In classroom-based scenarios, follow-up was intrinsic during the classroom hours. In the virtual learning scenario, special attention is needed on the follow-up with the students. In this course, the learning curve of each student was closely monitored, in addition to one-to-one video meetings with each student. Also, the students were divided into groups especially for the practical modules. Each group was assigned a professor especially for mentoring and follow-up of the students through a scheduled one-hour video meeting beyond the virtual-class timings.

5. Course results and impact

The new course of Biological Engineering Workshop 1 was started at the UdelaR in 2014 and was offered only at one of the regional headquarters of the university in the city of Salto, Uruguay. In 2016, due to increasing demand and popularity, the course was started at the university headquarters in Montevideo, Uruguay as well. Currently the course is given in parallel at the university headquarters in three cities — Montevideo, Paysandú and Salto.

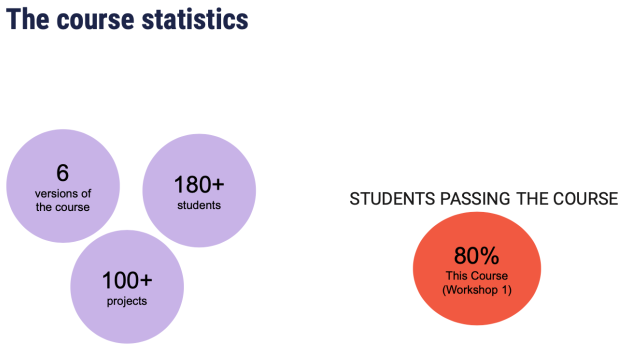


Figure 4. Key stats of the course (Biological Engineering Workshop 1) at the University of the Republic *(Universidad de la República)*, Uruguay

The first two years were dedicated to the modular designing of the course and its implementation started in 2016 (Figure 4). After four successful versions of the course, in 2020, the course was reengineered again by updating the course contents and teaching methodology, as well as the professors involved in the course. However, the key objective was the same, to use engineering as an innovative tool in the domain of biology and medicine, and to promote the transdisciplinary paradigm of collaboration. Throughout the course, the key objectives were met with respect to the expected outcomes. During the course, the students engaged in active learning during class-hours and peer-learning beyond the class-hours, involving active conversation with their peers and also with the professors of the course. The improvement of the students' scientific communication and presentation skills was notable, especially during the final project presentation with their posters. It was necessary to offer independence to the students to explore across the length and breadth of the life sciences to choose their own topic of interest for the final presentation. This was also particularly useful in introducing them to the research methodology and scientific techniques of literature review. The variety of topics for final presentation chosen by the students over the years ([14], *Appendix A*) illustrates the students' engagement with the state-of-the-art in the field, in an independent manner.

Throughout the theoretical and practical modules, students were exposed to a complementary approach to concepts and applications, especially illustrating real-world scenarios in a wide range of areas, spanning from eHealth to the Internet of Things (IoT), from the agricultural sector to biological systems. In the module of considering the human body as a signal generator, the students took part in an exercise measuring various signals from the body, which was illustrated with examples of where this technique can be applied, for example, the polygraph, and the motion-control of a car using physiological sensors (Figure 5). It helped the students to relate to the thematic concepts in an active way, rather than as a graph in a signal-viewing device.

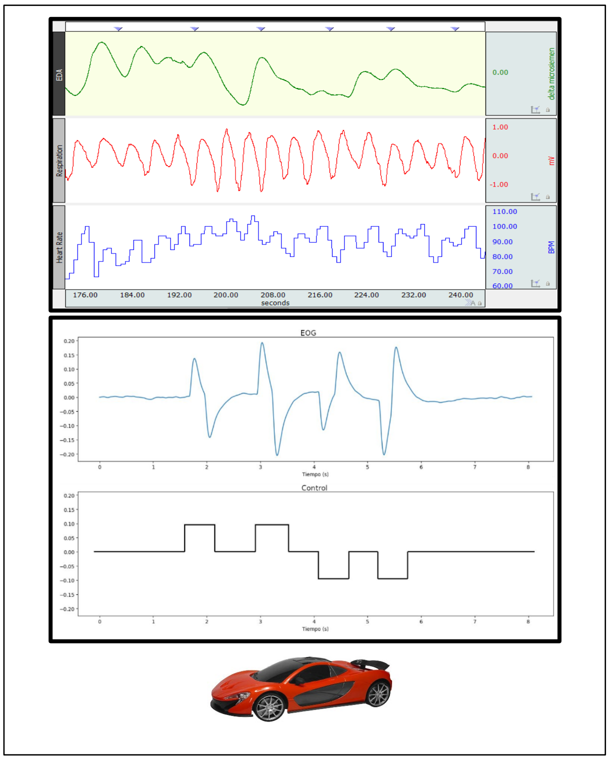


Figure 5. Experiments in practical modules — Biological Engineering Workshop 1 at the University of the Republic *(Universidad de la República)*, Uruguay

From the inception of the course, special attention was put on helping the students to develop scientific communication and presentation skills. Apart from the periodic presentations during the course and the final presentation, the students engage in science outreach activities in the university, including the annual science and engineering fair *(Ingeniería de Muestra)*, which is open to the public. The students present their projects, showing prototypes as well as their preliminary findings of their projects using posters. The scenario combines the ideas of poster presentation as in scientific conferences, and the illustration of student projects to a wider general audience. This significantly helped the students in gaining skills in communicating several applied aspects of biological engineering to both general and specific audiences. Also, students take part in extension activities of the universities like *Café Científico* (short informal discussions aimed at a wider general audience, highlighting key projects from the universities).

With the change of the course paradigm to virtual platforms, it was important to evaluate the impact of the change from both the perspectives of professors and students. With this intention, a survey was performed on the students and professors, almost in the middle of the course. The objective was to analyze the new format of the course and consider the shortfalls or issues during the process to resolve within the course-timeline itself.

After the survey, 60% of the professors pointed out that the cumulative class-hours in the virtual course have been more than the standard course. Despite the effective class-hours being reduced, the virtual modality of the course added extra student engagement opportunities like one-to-one follow-up, and group-mentoring, making the total course-hours more than the pre-pandemic situation. In this respect, 80% of the professors indicated a significant increase in their workload compared to the previous course format. Special care taken in the preparation of the materials prioritizing student engagement in a virtual format tantamounted to the increase in workload. Also, this affected the distribution of work, as professors spent more time on the preparation of courseware and student-interaction than the actual class lectures (Figure 6). This was recognized by 90% of the students, who positively opined about the increase in the intensity of professors' work and dedication toward the course compared to pre-COVID-19 times.

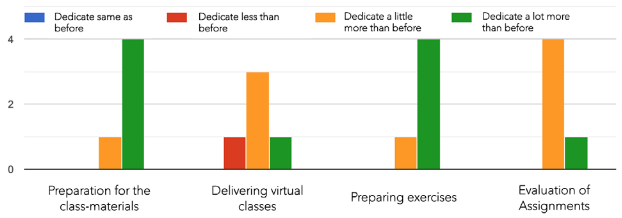


Figure 6. Survey of professors — time distribution — Biological Engineering Workshop 1 at the University of the Republic *(Universidad de la República)*, Uruguay

With the new virtual modality, a key challenge was the technological disparity prevalent within the students, making it difficult to follow the course in a similar pace or form (Table 4). Several measures like providing video-recordings (optimized quality) of classes and one-to-one sessions were taken to allow students with limited technological resources to follow the course. Also, all the professors acknowledged a disparity among the students with respect to adaptation to the new paradigm leading to more student-issues than before. The lack of face-to-face meetings and performing the group projects virtually was a substantial component of the student issues when working in groups. Interestingly, all the professors indicated that, despite having difficulties in adapting technologically to the virtual modality, the students adapted adequately to the new paradigm over a period of two months.

Table 4. Technological disparity in students in virtual learning

Variable		Possess	Do not posses
Technological aspects	Availability of computer (sufficient) in home	84%	16%
	Availability of good internet connection in home	68%	32%
	Availability	100%	0%
Other aspects	Suitable and calm place to study	84%	16%
	Adequate physical space to study	84%	16%
	Share space with other people with virtual work/study	53%	47%

Though the professors are divided on whether the course should go back to its previous form after the pandemic (60% no, 40% yes), all the professors agreed to incorporate more multimedia materials in the courseware to enhance student engagement.

The impact of special follow-up in the new learning modality was another important factor to analyze especially from the students' perspective. The professors of the course have emphasized the value of one-to-one follow up with the students since most of them do not turn on their cameras during virtual classes (95% of the students expressed it should not be compulsory for them to turn on video during live virtual classes); the personal follow-up was therefore important to connect actively with the students. The professors also noted that the difficulties in working in groups occurred more in the new virtual setting for the course than the previous classroom-based versions. With respect to the process of learning in the new virtual format, 58% of the students expressed a satisfactory level of learning, whereas 26% and 16% of the students expressed high and low levels of learning respectively (Figure 7).

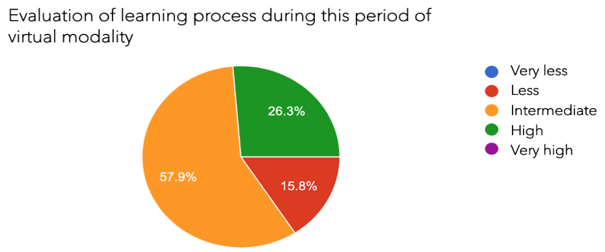


Figure 7. Survey of students about the virtual learning process — Biological Engineering Workshop 1 at the University of the Republic *(Universidad de la República)*, Uruguay

However, the students have expressed their issues with the practical modules in the virtual format. The practical lessons are given through video recordings and the students expressed their preference for classroom-based live practical sessions, since most of the practical elements of the course were meant to be performed in a classroom, using physical devices.

In addition, the average performance of the students has been analyzed over the years across all the versions of the course delivered (Figure 8). Intermediate evaluations of student-performance in 2020 have also been put together, to analyze the impact of the change to virtual courses during the COVID-19 pandemic, and how it affected student performance.

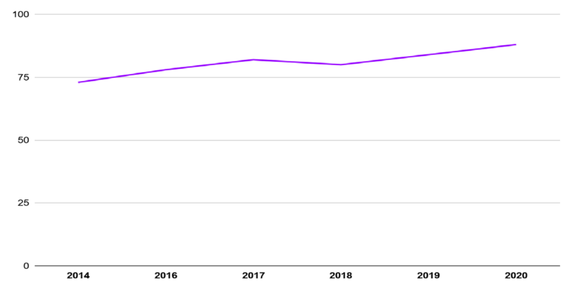


Figure 8. Performance of students: Years vs Average score of students by percentage — Biological Engineering Workshop 1 at the University of the Republic *(Universidad de la República)*, Uruguay

Based on the progression of student performance, it is evident that the continuous improvements in the course contents and teaching methodologies have positively impacted student results. Interestingly, even in 2020 with the change to a virtual setting, student performance didn't decline, improving to 88.4% compared to 84% in the previous year of 2019. Also, in all the versions of the course, the students maintained a score of 70% and above, which indicates a good level of performance across the years.

6. Discussions and future scope

Many countries across the world are reviewing their scientific training careers at the university-level and the way in which the new pedagogical paradigms are applied [10]. Especially at the regional level in South America, the academic sector of biological engineering has always suffered a large gap between knowledge and innovation. As most of the real-world problems and projects in this domain belong to the Pasteur Quadrant classification [8], innovation takes a key role in this. This poses an ongoing holistic challenge in the context of pedagogy and teaching methodologies, to engage students in new ways of acquiring knowledge, communicating and collaborating on a par with the global community, blurring the boundaries of each field and delving into a transdisciplinary space.

The new approach toward the introductory course of the undergraduate program of biological engineering in the University of the Republic (UdelaR), Uruguay has actively changed the performance and involvement of the students in the field. Despite the course being designed with a transdisciplinary approach to biological engineering, it could be scaled to other introductory courses at the undergraduate level of the university, considering the issues faced by first-year students are mostly similar in several universities across the world [10]. However, it has been observed through the experience of this course that such courses need a fast and regular update to their knowledge element to keep up with the state-of-the-art while overcoming the challenge of ensuring the ease of study at the same time. There is also a need for professors working in transdisciplinary areas to share their vision to new students in order to engage them with research and innovation right at the beginning of their university program and supply them with the necessary transferable skills to solve real-world problems. With the restructuring of the introductory biological engineering course into a virtual format due to the COVID-19 pandemic, several aspects of the teaching-learning paradigm changed. However, based on the surveys on students and teachers in addition to the regular evaluations, a satisfactory level of learning and performance could be maintained, mostly focusing on enhanced student engagement during live virtual classes and strong personalized follow-ups with the students. The new outcomes from the virtual setting point to a need of reengineering the existing learning paradigms and adapt more toward blended learning. With the changing direction of pedagogy and research across the world, it is quintessential to adapt university courses to the same, promoting an environment where the scientific and engineering disciplines merge and the learning methodologies lead to a ubiquitous learning [9] environment.

Appendix A. Poster Topics

Topics chosen by the students for their final presentation of the Biological Engineering Workshop 1 at the University of the Republic *(Universidad de la República, Uruguay)* between 2014 and 2020.

2020

- Genetic modification in human embryos
- Ectogenesis: the future of human reproduction
- Organic retinal prostheses
- Hybrid Living Materials
- Technology comes to the oceans
- Treat tremor with ultrasound waves
- Exoskeleton
- Silk as a biomaterial
- Optimization of the plastic degradation capacity of a bacterium through directed evolution.
- Batteries made by genetically engineered viruses.
- Biofabrication.
- AlterEgo: artificial intelligence can be an extension of your mind.
- Bioinformatics and genetic therapy: tools for the diagnosis and treatment of rare diseases.
- Patient specific artificial hearts.
- Optogenetic dissection: new treatment for psychiatric diseases
- Contact lenses with augmented reality
- Genomics saving lives and crops in Africa
- Use of nanotechnology in amyotrophic lateral sclerosis
- Technologies vs. Spinal injuries
- Brain-Computer interface using an EEG device.
- Agriculture of the future
- Crop genetic editing
- Neuro-enhancement
- Prevention of vein graft failure
- Endometriosis control
- Neural stimulation prosthesis

2019

- Application of Artificial Intelligence in Radiographs.
- Light: The medicine of the future at the service of our brain.
- Present and future of bioprinting.
- T-cell immunotherapy with CAR: the definitive cure against cancer?
- Phantom organs, the future of implants .
- Deep Brain Stimulation.
- Regenerate with the future.
- Laboratory on a chip: Early detection for cancer.
- Brain implant to convert brain signals into words.
- Graphene: The Armor of the Future.
- Mobility for those who do not have.
- Brain-Computer interface. First step for technological immortality.
- 3D printed lungs.
- Use of BCI and BSDS devices in people with communication difficulties: a special look toward emotional understanding.
- Focused Ultrasound guided by Magnetic Resonance.
- Toward a science without animal experimentation.
- Portable ECG to detect relevant electrical disturbances.
- Self- sustaining Biological Implants.
- 3D printer: a tool to innovate.
- Nanotechnology: The cure to the incurable.
- Genetic Engineering for Medicine.
- Specific patient medicine.
- Super Humans with Prostheses.
- Save lives — Donate the umbilical cord.

2018

- Health and technology are biocompatible.
- Description of sheep growth through mathematical models.
- Optogenetic: Illuminate your mind.
- Biomechanical model of the trachea for the diagnosis of Parkinson's disease.
- Advances and uses of electronic skin.
- Brain monitoring to improve the quality of life.
- Low cost prostheses.
- Wearable Microfluidic Device for the capture, storage and colorimetric analysis of sweat.
- Nanotechnology: the hope of oncology.
- Restoring the rhythm: automatic external defibrillators available to everyone.
- Application of Artificial Intelligence for the estimation of heart rate from videos showing faces.

- Spider silk: "The material of the future".
- Brain-computer interface.
- Diapers inspire a new way to study the brain.
- Otoacoustic Emissions. The power of a neonatal diagnosis.

2017

- Retinal prostheses and intraocular implants to correct blindness.
- Application of thermography in the diagnosis of breast cancer.
- Molecular images of the breasts.
- White coat hypertension and its detection.
- Brain mapping: research processes and importance in the scientific and health fields.
- Transcranial Magnetic Stimulation.
- Bioinformatics at the service of pharmacovigilance.
- Artificial Heart. Ventricular assist devices.
- Da Vinci surgical system.
- Brain / computer interface and neuro-prosthesis applied to quadriplegic people.
- Robotic surgery: its development and evolution.
- Bionic kidney.
- Bionic Engineering: a new life opportunity.
- Cyborg Beast: Low cost prostheses for children.
- The 3D printer as a tool in medicine.
- Printing of 3D ovaries and nano-robots to combat infertility.
- GPS technology in sports.
- Purification of ambient air.
- Graphene: the material of the future.

2016

- Biomagnetic signals – Alzheimer's Disease.
- Human connectome.
- Bionic eye.
- Water
- Touch in prostheses (sensitivity).
- Mems.
- 3D printing, fabrics.
- Biochips.
- Biodegradable Electric Generators for the feeding of Medical Implants.
- DEKA Bionic Arm.
- Light and its effects on the SN.
- Neonatal incubator for developing countries.
- Cyborg Beast: robotic hand.
- Retina Implant.
- Mind reading.
- Pre-Hospital Care Robot.

2014

- Bio 3D Printing of Blood Vessels.
- Arrhythmia detector vest.
- 3D printing, revolutionizing medicine.
- Healthy energy.
- Mass DNA sequencing: path to the medicine of the future.
- Bionic eye implants.
- Photovoltaic roads.
- See with your hands.

Acknowledgements

The authors thank all the current students of the course Biological Engineering Workshop 1 for taking the surveys and participating actively throughout the course.

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