Teaching rock mechanics using Virtual Reality: laboratory practices and field trips during the confinement of the Coronavirus COVID-19 in Ecuador, Bolivia, and Spain

M T García-Vela¹, C P Borja-Bernal²,³, L Jordá-Bordehore⁴, R Medinaceli-Torrez⁵, S Loaiza¹, D A Falquez¹

¹Facultad de Ingeniería en Ciencias de la Tierra FICT Escuela Superior Politécnica del Litoral ESPOL Vía Perimetral 5, Guayaquil, Ecuador
²Universidad de Guayaquil Avenida 10 NO, Guayaquil 090613, Ecuador
³ETSI Minas y Energía. Universidad Politécnica de Madrid. Calle de Ríos Rosas, 21, 28003 Madrid, Spain
⁴Escuela Técnica Superior de Ingenieros de Caminos, Canales y Puertos. Universidad Politécnica de Madrid. Campus Ciudad Universitaria, Calle del Prof. Aranguren, 3, 28040 Madrid, Spain
⁵Universidad Técnica de Oruro, 6 de Octubre y, Oruro, Bolivia

mistagar@espol.edu.ec

Abstract. Virtual Reality (VR) consists of creating spaces similar to reality where the viewer interacts more or less in a digital world. This digital world can be programmed so that geosciences student takes data as if it were a field trip. The VR can save money, logistical problems and avoid accessing unsafe places. Besides, students can access places that would otherwise require a veritable expedition (hydroelectric projects in the Andes, remote highways, dams, tunnels in the Himalayas, among others.). At the beginning of the project in 2019, we designed some virtual rock mechanics classes to complement the face-to-face classes: In recent years, we have seen it increasingly difficult to organize field trips. We have designed virtual scenarios where students can obtain geomechanical data from tunnels, mines and rock slopes. We have used the CoSpaces commercial platform for this purpose. Within this virtual world, we place photographs, pop-up menus, videos of field and laboratory tests and clues for the student to search the data for himself in a quasi-real scenario. With all this data from the virtual scenario (as if they were in the field trip), students interpret in the cabinet and perform complex calculations (Hoek Brown, Barton-Bandis criteria, RMR, Q index, among others). We have generated two types of virtual classes: laboratory practices and field trips. Since mid-March of this year 2020, there is no face-to-face teaching in many world faculties where rock mechanics, rock slope engineering, tunnels, and underground mining subjects need to be taught. Thanks to these Virtual Reality laboratories, we have been able to carry out our teaching successfully. Combining two means: VR and software, have allowed making classes very practical and realistic, and the students have highly valued this initiative. Besides, rock mechanics plays a very important role in the safety of underground works and excavations. The best way to learn methodologies in risky environments is undoubtedly using simulators. In the same way that pilots and astronauts practice stress situations in simulators, we consider it useful to use Virtual
Reality and simulators to learn how to map rock mechanics and stability in mines and tunnels. It is an advance in security and quality training.

1. Introduction: Problems identified

1.1. The decrease in field trips in the new syllabus. Role of New Technologies

There has been a decrease in field trips in all teaching fields of earth sciences and related careers (engineering, environmental sciences, and others). On the one hand, with the new study plans, careers are shorter - one to two years less in engineering (compared to the 5-6 total that existed until the 1990s). Various mobility issues and responsibilities have limited this type of offers by teachers and departments. In many careers, field trips have been completely suppressed. Obviously, not geological careers, but others in which this type of formation has not been considered crucial.

New technologies allow us to resume field trips in the "virtual laboratory" format [1]. In recent decades it has been sought to fill these gaps through videos on the Internet recently. However, as we understand, a video is not an interactive activity in which the student observes, draws, and interprets in a tutored way, and the teacher can correct them on the fly. The student is a passive agent in this type of class with audio-visual material. The student must participate in this fieldwork, taking the data and then doing the desk calculations. Given the extreme difficulty of replicating the field, what can be done is to include clues or provide certain data in a virtual environment. New technologies provide the necessary tools for this task.

1.2. Access to courses and educational material by professionals working in camps and remote locations

Excepting Scandinavia, remote locations are nowadays unusual in Europe. Normally European construction sites and mines are relatively accessible. Usually, there are towns and lodgings within a reasonable distance, no more than two hours' drive away. Weekends workers can easily return home. Construction and mining camps are an exception.

However, this is not the case in remote territories of the world, such as the Arctic, Africa, the Andes of South America, jungles, desert oil camps, etc. The only access roads are those built for the project. There are no towns with the minimum services within a reasonable distance/time radius in driving hours, and there is even no access by road (plane or helicopter). Cities are the only sources of supply for certain inputs and are very remote. They work in shifts in these places, a few weeks, or a month in a row in the place without leaving and leaving off days off, from 4 days to several weeks depending on the shift.

In these work environments, technicians have enormous difficulties attending and taking advantage of specialization and postgraduate courses. Mainly in the mining and oil worlds, monographic courses on highly specialized topics are very successful. These courses are delivered as on-site training. The specialist – a trainer, travels to the facilities and gives a very specific course on an intensive basis and stays at the camp during that time, which is feasible when the person who moves is interested in offering a service. However, it is not usual for an academic to travel to teach courses of a certain duration. Very often, geologists and engineers try to follow postgraduate courses on their days off. In some Andean countries such as Ecuador, Bolivia, and Peru, it is common to teach intensively on weekends or 3-4 successive days - leaving a week off in between. However, this kind of highly intensive training – sometimes 8 hours a day – is not very didactic: students are tired of the trip on their first day, with little or no time to consolidate concepts and usually with a lot of work back the mining site, which entails a disconnection from the course during the intermediate periods between lessons and difficulty performing the exercises.

1.3. Difficulties of the field briefing

The use of VR can also help improve actual field trips. It can help us give a first virtual explanation of the place to visit is like, its risks, and the areas to observe. It would be a kind of "virtual briefing". It is difficult to be effective when we access the outcrop to explain how to identify the key elements that we
will analyze later for the first time (figure 1). The first lessons on the slope or site with large groups of students are confusing and may not be heard. An introduction in the classroom - virtual - to the place of study and then a real work on the site in small groups where the teacher tutors personally going from group to group may be more advisable. Students virtually receive useful prior information to avoid being "lost in place" and not having problems listening to the briefing on the field when there is wind, cold, environmental discomfort, etc.

![Figure 1. Briefing to introduce mapping outcrops and mines. a), c) Explanation of the filling mode of a geomechanical field template in a mine entrance (Trujillo, Peru). b), d) Briefing at tunnel entrance-face mapping, in an abandoned teaching and training tunnel, Centromin, Lima (Peru).](image)

1.4. Online training and resources on the Internet in recent years

Until a year ago, the Internet was a source of information but not a preferred channel for teacher communication (except email). Business video conferencing and Skype paved the way for the revolution that would come - unknowingly - in March 2020. Virtual laboratories and some virtual field tour initiatives have recently incentivized students and complete teaching aspects that could not be seen in class. They were also introduced to initiate students into expensive trials and techniques. In this sense, the question that arises is: if aircraft pilots and doctors use simulators, why not use them also engineers and geologists in the academic world and thus be better prepared to visit a factory, road slope, outcrop, or tunnel?

2. Teaching experience: Virtual reality and virtual worlds as a fundamental part of learning geosciences during confinement and post-COVID

2.1. Background of our initiative
We were evaluating the possibilities of improving a little and making teaching more attractive with a lesson supported by VR when the coronavirus crisis broke out in Spain and the rest of the world between February and March 2020. VR has gone from being a timid companion in class or an idea for the future to become a reality, and it has saved us many courses. VR was initially designed to improve teaching, but it became the only instrument for teaching some subjects: laboratories (soil and rock mechanics, mineralogy, petrography, topography, drilling, etc.). Laboratory practices or field trips can no longer be carried out, and those pending were suspended.
2.2. Why Make Geosciences Field Trips Virtual?

Description of the experience. Beginnings and change of direction of the project: The initiative begins in October 2019 as an educational innovation project. From October 2019 to March 2020, photographs and data are taken in the field, and the first "virtual field trips" are implemented in the COSPACES commercial platform. This platform has two kinds of scenarios: 360° images or partially immersive 3D environments. In both cases, we have put the activities as drop-down pop-up menus in which properties of the materials and clues are indicated to solve exercises imitating the data that the student could obtain in a supervised field trip.

We generated some very first virtual scenes which replace or complement the data collection in a real place: tunnel, work, outcrop. The student performs the exercises taking as starting data information that extracts from an environment that simulates reality. The rest of the task is carried out conventionally: solving exercises with the extracted data. The innovation resides in that until then, the data of the problems come as a list or statement; now, it is the student who must look for them in an environment that simulates reality.

On March 5, 2020, a tunnel class was held in a computer room where the virtual scenario prepared was tested for the first time (table 1). Each student has a computer, and they are provided with various templates to collect data in the virtual tunnels and solve exercises on rock mass quality - RMR and Q - and tunnel stability. The teacher acts as a facilitator. The students access the VR platform, and the teacher shows each of the scenarios on a shared screen. On March 11, classes were suspended at the Spanish university, and then the state of alarm and confinement of the population was declared on March 14, 2020. The rest of the story is similar in almost all countries globally: more than 1000 million students stopped their classes. The application we use of Virtual Reality changes from being a "teaching improvement" to being one of the main channels of the subject of tunnels and rock mechanics.

2.3. Experience 1: Data collection and mapping in virtual outcrops and tunnels (Master's degree in Polytechnical University in Madrid, Universidad Nacional del Altiplano, Puno Peru and ESPOL Ecuador)

In recent years, mapping workshops and data collection in the field, in mines, tunnels, and outcrops, have become very popular in the Andean zone's mining countries. The Pandemic has nipped this possibility at the root. The workshop we propose is based on the application of a commercial platform of Virtual Reality. The student can map in the application as if he were in the outcrop or the mine. The templates to fill in are downloaded outside the application so as not to saturate it with information. There are different scenarios with different degrees of difficulty; in some, the pop-up menus are directly the data that we enter in the calculations. Students find authentic field data in other more difficult and achieved scenarios (Joint Roughness Coefficient, sclerometer rebounds, compass measurements recorded in videos and photographs) that they must interpret before using it in calculations. We use "avatars" to move through the different scenes and guide the student.

2.4. Experience 2: Virtual diamond drilling - core logging (Master’s degree classes at the Polytechnical University of Madrid)

The practices of drilling core boxes logging are very popular in tunnel and rock mechanics courses. We have taught them with real core boxes in Bolivia, Peru, Ecuador, and Spain. The students are grouped into 2-4 individuals around the box and log it using a template. During the confinement of the Pandemic, we have carried out the practices with virtual boxes. We replicate these boxes in 3D using the Structure from the Motion photogrammetry technique [2] (figure 2). Once the virtual box has been created in the most suitable format, students can view it in an online repository - in this case, Sketchfab [3]. We also save them in pdf 3D format so that they can be downloaded and stored. Students analyze the box in the repository and fill in the template digitally or physically. It has been a very well-received practice during
the Pandemic, and the educational results were good. Due to the difficulties of carrying 20-30 Kg boxes to the classroom, we think this initiative will last after the pandemic issues.

Figure 2. Strategy to generate a 3D core box from Structure from Motion photogrammetry strategy.

2.5. Experience 3: Virtual Laboratory Practices Faculty of Engineering Geosciences (FICT – ESPOL, Ecuador)

Face to face teaching was not possible during most of 2020; this situation remains at the moment. That was the motivation to implement a virtual laboratory teaching method that is as close to reality, didactic and attractive to students.

Cospaces EDU platform was used to virtualize the laboratories facilities and laboratory practices of six laboratories of the Faculty of Engineering in Earth Sciences (FICT) of the Escuela Superior Politécnica del Litoral (ESPOL).

The Geotechnics and Construction Laboratory is between these six laboratories. Undergraduate students of civil and mining engineering careers make lab practices regarding rocks, soils, and construction materials. Cospaces EDU has allowed virtual reality (VR) augmented reality spaces (AR) to be created. Through its CoBlocks coding programming language was possible to program VR and AR in which users can interact with the spaces and follow the steps in the same order that in presential lab practices. Besides, the Merge Cube add-on available on the platform was used to create AR spaces.

Figure 3. a) Augmented reality space - "Tunnel", using a Merge cube; b) Geotechnics and Construction Laboratory' virtual replica projected over a surface.
In the Geotechnics and Construction Laboratory, 21 practices were virtualized between these seven are related to rock mechanics used in Soil and Rock Mechanics, Mining Geotechnics and Mechanics of Geological Materials subjects. The Laboratory practices virtualized regarding rock mechanics: (i) Estimating rock strength by the rebound hammer, (ii) Tilt test on rocks, (iii) Rock Unconfined Compressive Strength (UCS), (iv) Split tensile test on rock specimen, (v) The apparent density of rocks-saturation method, (vi) The apparent density of rocks-paraffin method, and (vii) Rock Quality Designation (RQD).

The methodology for the creation consisted of three phases, which are design, implementation, and validation. The virtual spaces were integrated through the university's Learning Management System (LMS), named SIDWEB. The Laboratory has its repository in the SIDWEB structured for each virtual laboratory practice (VLP): link to CoSpaces EDU laboratory practice, test procedure guide, safety guide, a slideshow of the laboratory practice, raw data sheet, enabling the user to access the information anywhere and anytime.

During the design phase, the laboratory technicians' expertise, full knowledge of the standard, specs of the laboratory equipment, plan of laboratory facilities and data from real experiments, was used in conjunction with a robust block-based programming skill to carry out the VLP. Besides, because Cospaces EDU allows uploading 3D models, 3D CAD software was used to replicate the laboratories' equipment and facilities. During face-to-face education, the students were given the following documentation prior the attending a practice in the Laboratory: practice procedure, blank data sheet, safety guide. The following methods are used in some VLP to encourage the user to read the documentation during online teaching:

- In most practices, a questionary is showed at the VLP's beginning, which does not allow the user to continue to the next step until a minimum score is achieved.
- Bubble text – free VLP, so the user does not indicate "where or when to click" to move forward on the VLP.
- In some VLP, indications are given using bubble text pointing at the object that needs to be clicked on, activating a piece of equipment, or moving forward in the virtual space.

2.6. Experience 4: Topography classes, Faculty of Natural Sciences (Universidad de Guayaquil, Ecuador)

The state of exception established in Ecuador caused face-to-face classes in all the country's universities to be suspended, causing teachers and students to go from a face-to-face modality to an online one within a few weeks. This change caused modifications in the teaching-learning method, and the applicable regulations and forms of qualification changes that to date have brought great challenges to the institution and the university community. Technical careers have been the hardest hit by the Pandemic. They have had to look for alternatives applicable to teaching methods, techniques, and instruments commonly used in the field, finding virtual and augmented reality a good alternative for teaching subjects related to geosciences. In the topography classes, the use of simulators available online was implemented, which required the student to acquire previously, through virtual classes, electronic files and online videos knowledge about topographic equipment and manipulation techniques. The virtual platform requires that the student solve sequential exercises on equipment in 3D graphics. In case of not completing the challenges, the user must return to the notes or class videos to later continue with the proposed practices; this sequential work serves to generate the effect rebound and that the topics discussed are reviewed again, thus increasing the theoretical and practical knowledge of the topic. The following table summarises the resources created during this year 2020-2021.
Table 1. Virtual Reality resources created.

| Space | Link | Type            |
|-------|------|-----------------|
| Virtual tour 3D | https://edu.cospaces.io/GAG-GGR | Virtual Tour |
| The apparent density of rocks- paraffin method | https://edu.cospaces.io/BSJ-FGE | Laboratory practice |
| The apparent density of rocks- saturation method | https://edu.cospaces.io/FWH-NBS | Laboratory practice |
| Rock Quality Designation (RQD) | https://edu.cospaces.io/VJK-STB | Laboratory practice |
| Estimating rock strength by the rebound hammer | https://edu.cospaces.io/LMH-NRU | Laboratory practice |
| Tilt test | https://edu.cospaces.io/RCC-WLM | Laboratory practice |
| Rock Unconfined Compressive Strength (UCS) | https://edu.cospaces.io/ENE-BKD | Laboratory practice |
| Split tensile test on rock | https://edu.cospaces.io/KND-PWX | Laboratory practice |
| Rock Mass Classification in tunnels | https://cospac.es/md40 | Field trip |
| Rock engineering laboratory | https://edu.cospaces.io/EPD-NHY | Laboratory practice |
| Rock Slope engineering | https://edu.cospaces.io/KTU-APD | Field trip |

3. Conclusions

3.1. Implementation of virtual practices in teaching

Implementing the virtual Laboratory in learning was developed in a complementary way and parallel to theoretical approach content. The use of additional resources to the virtual Laboratory, such as videos of the development of physical laboratory practices executed in previous academic periods, has been beneficial based on the experience gained. The difficulty encountered in the project's execution lies mainly in the technological resources that the student must carry out laboratory practices. Thus, students find it more challenging to perform the practice from a cell phone or tablet. The student has identified the need for compliance with a prior reading of laboratory practice guides.

Collaborative work in face-to-face practices is undoubtedly a strength; however, virtual learning has sought tasks that allow group work by performing the practice in groups, executing the different steps of internships by different students and processing and analyzing data in a group way.

The inclusion of security parameters in virtual lab practices has been useful. The student intuitively seeks to take security implements before executing activities that require it.

Another critical factor is the execution time of practices in the Laboratory. It is significantly reduced, achieving a complete practice in a few minutes, taking a few hours and even days to complete its complete execution in the physical Laboratory.

The importance of analysis and the proper use of experimental data globally and real cases is undoubtedly one of the laboratory practices' objectives. Therefore, the realization of virtual practices is
focused on making known to the student the existing and standardized methodologies for obtaining data, which must be used for engineering decision-making. Under no circumstances may they replace the development or improvement of acquired skills such as handling instruments, tools, or devices to take measurements in the Laboratory or on-site. However, the ability to discern consistent data and results, analysis, and interpretation results are entirely achievable with virtual labs implementation.

3.2. Laboratories and field trips in the near future
Virtual Reality (VR) techniques combined with teleteaching can significantly reduce CO2 emissions and ecological footprint, avoiding a multitude of unnecessary displacement. In the case of laboratories, agglomerations of large groups can be avoided and, we can focus on individuals online instead of classical laboratory practices where only a part of the students pay attention.

Practices can be divided by making a virtual introduction where the equipment is explained and more linked with theory and security measures. And then the "conventional" practice develops. Practice can be lengthened with longer virtualized trials or the inclusion of augmented reality in the classroom.

3.3. Towards the ideal virtual classroom
Virtual worlds have come to stay. Now they are completely essential to keep many subjects and laboratories "afloat". In a post-pandemic future, virtual worlds will support classes in a mixed format: face-to-face - online. Obviously, we do not know what the ideal virtual classroom format is, but throughout this first year of the Pandemic, we can highlight some important aspects:

• Prepare the class using recorded previous classes and reference material
• An online class composed of blocks of 10 - 20 minutes
• Use Virtual Reality to change the scene and make the class more bearable. Break the monotony. Guide the student through the virtual scenario so that they become familiar with it
• Do not saturate the virtual environment: use Moodle-type platforms where you can download templates. Combine the virtual scenario with Kahoot type quick tests.
• Do jobs
• Do a tutorial or feedback of the Virtual exercise

4. Acknowledgement
This project has been carried out within the framework and support of an Educational Innovation project of the University Polytechnic of Madrid-UPM 2020: AULA-GeoVirtual: Field practices - virtual laboratories of tunnels and rock mechanics (IE1920.0410)

References
[1] Jordá Bordehore L, Jiménez Rodríguez R, Senent Dominguez S, González Tejada I, Galindo Aires R A, González Galindo J, Reig Ramos M I, Soriano Martínez A, Gutiérrez-Ch J G, García Luna R, Tomás Jover R, Cano González M, Riquelme Guill A, Pastor J L, Romero Crespo P L, Borja Bernal C P 2020 Salidas de campo virtuales en asignaturas de Ingeniería del Terreno, In: Roig-Vila R, Antolí Martínez JM, Diéz Ros R (Eds) Redes – Innovaestic 2020 Virtual Congress XVIII Jornadas de Redes de Investigación en Docencia Universitaria-REDES 2020 Alicante, Spain (In Spanish)
[2] Jordá Bordehore L, Riquelme A, Cano M, Tomás R 2017 Comparing manual and remote sensing field discontinuity collection used in kinematic stability assessment of failed rock slopes. International Journal of Rock Mechanics and Mining Sciences. 2017, 97: 24-32.
[3] Jordá Bordehore L virtual repository, access 09/02/2021 https://sketchfab.com/3d-models/drilling-core-box-num85-a73ec61c977847f294deae7d6802522f
[4] García-Vela M, Zambrano J, Falquez D, Pincay-Musso W, Duque K, Zumba N, Barcia M, Méndez J, Valverde P, Romero-Crespo P, Jordá-Bordehore L. Management of Virtual Laboratory Experiments in the Geosciences Field in the Time of Covid-19 Pandemic. ICERI2020 Proc. 2020;1(November):8702–11.