

Thinking outside the box – virtual labs in engineering education

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Abstract

An important part of engineering education is training in laboratories. If done correctly, such a hands-on approach is much more effective than pure lectures, where knowledge is only passively absorbed. The traditional lab is usually on-site, requires students to be on campus, and learning content is limited to the particular focus of that institution. For this reason, five European universities have formed a partnership and developed a joint platform that offers experiments that can be experienced in virtual labs and accessed repeatedly. This way students profit from the expertise of different institutions, while gaining intercultural work experience. Additionally, virtual labs reduce the immense expense of student mobility, are more inclusive towards minority groups and lower costs for universities in the long term.

Keywords: *virtual labs; engineering education; structural engineering, virtual access to experiments.*

1. Introduction

The COVID-19 pandemic had a huge impact on teaching and teaching methods: from one day to the next physical attendance on campus and in the classroom was no longer an option. This posed various challenges to the different disciplines as new, digital teaching formats had to be created in a rather short amount of time. While the humanities and social sciences were able to hold synchronous classes online relatively easily via conference tools, or convert teaching materials into asynchronous e-learning modules, the engineering disciplines were faced with the challenge that a vital part of their curricula consists of laboratory experiments. These are often devised for a better understanding of theoretical knowledge taught in lectures and vital in the education of future engineers. Laboratories can lead to a substantial learning success among students that is difficult to achieve in other traditional learning environments or didactic situations. Therefore, implementation of digital learning is only successful if laboratory experiments are included in digitalization efforts.

Another setback for a comprehensive education was that suddenly exchange programs could no longer take place. Giving students the chance to extend their education to fields not offered at their home university has been part of the teaching program of several European universities. This led to a partnership with a strong exchange between participating departments. Such partnerships among European universities had always required students to travel to different locations to have the chance to participate in experiments offered by different universities. However, the overall expense of student mobility is immense (Johri & Jesiek, 2014) and may exclude students from lower income backgrounds (Ackers, 2010; Rodríguez et al., 2011) or countries with with a lower income level (e.g. eastern European countries) unless fully sponsored. Students with a disability are also at a disadvantage.

The pandemic offered the chance to rethink teaching options and make excellent education more easily available to all students. The PARFORCE project has executed this by bundling the expertise of different partners across Europe and providing students with access to different facilities from their home computers or by using facilities at the university in their home country. Creating virtual labs made it possible for students to expand their knowledge beyond the area of expertise of their home university and beyond individual personal restrictions.

2. Project PARFORCE

2.1. Strategy and objectives

Five European universities across different countries have formed a strategic partnership within the framework of Erasmus+. Two universities are situated in Germany (Bauhaus-Universität Weimar and Ruhr-Universität Bochum), one in Croatia (University of Osijek),

one in North Macedonia (Institute of Earthquake Engineering and Seismology at the Ss. Cyril and Methodius University in Skopje), and one in Portugal (Universidade de Aveiro). Each partner university has a different focus. This is often based on their respective geographic situation or the different demands that are placed on local structures (e.g., earthquake-prone, growing, i.e. climate-related exposure to fire effects, wind as an impact and as a resource). Together, they developed a common platform for digital/virtual laboratory experiments to support higher education in European civil engineering and contribute to the students' understanding of course content.

The availability of various laboratory experiments that are not part of the standard education at each university is the main objective of the project. The experiments planned in this project are: boundary layer wind tunnel experiments, non-destructive and destructive experiments on a shaking table, and fire resistancy tests. The project applies the concept of immersive 3D representations for detailed and realistic visualization in virtual reality to the performance of laboratory experiments in the context of higher education in civil engineering.

2.2. Local labs vs. Virtual labs

A laboratory is understood as a scientific or technological environment in which scientific or technological research, development experiments, tests or analyses are conducted (Terkowsky et al., 2020). Technical laboratories are used to build, develop, and test technical solutions, processes, and products. Laboratories in engineering education can be used for empirical research to observe, measure, test, analyze, and especially to develop understanding. Unfortunately, the use of local labs in engineering education is limited due to severe time constraints and their highly specialized nature. In addition, these laboratories require students to be physically present on site. Zutin et al. (2010) point out that the inefficient use of expensive and highly sophisticated and specialized equipment that is common in traditional laboratories can be overcome by providing online labs to learners as technology-enhanced learning environments. Virtual labs offer several advantages over traditional labs, including almost unlimited time availability, interoperability, reusability, and location-independent access. Online labs do not require the learner to be present on site, but can provide an experimental experience that is accessible from the learner's location, regardless of the distance to the institution.

2.3. Shortcomings of labs

Laboratories can offer educators the opportunity to provide students with a learning environment where they can creatively solve engineering challenges designed to facilitate competencies required of engineers in the digital age. Degree programs as mechanical engineering aim to prepare students for the highly practical nature of their future careers, in addition to providing them with a scientific background.

Planning and conducting experiments in the laboratory are among the typical tasks of graduates. For this reason, it is important for them to gain experience working with full-scale equipment while still studying. This includes e.g. printers for additive manufacturing, prefabrication lines, or equipment used for long-term testing, such as a wind turbine with a Structural Health Monitoring system installed.

Engineering laboratories have great potential to activate and develop competencies that go beyond the conventional knowledge and skills that can be acquired in traditional classroom settings. However, they often fail to provide additional learning objectives (Terkowsky et al., 2020). Many laboratories present students with tasks and topic descriptions that clearly describe of a problem and a well-defined solution strategy. Of course, this is in stark contrast to many challenges in an engineer's professional life, where neither the problem nor the solution is explicitly known in advance. Thus, this approach of strongly guiding students contrasts with the aim to produce competent, self-organized and self-controlled engineers.

3. Virtual labs

Appropriate learning objectives are the starting point when planning an engineering education environment. Providing engineering labs requires appropriate facilities, equipment, and staff. As a result, they are often more costly than traditional classroom environments. Making such labs available as virtual labs involves monetary costs for technical equipment and infrastructure. In addition, time is required for didactic planning. However, these costs are quickly offset by the virtual lab's unlimited scalability and permanent availability.

The use of physical and virtual laboratories in engineering education curricula requires a rationale for how student work in laboratories and how this can complement the learning objectives of traditional classroom settings. Therefore, the formulation of learning objectives should emphasize the importance and potential of laboratories for engineering education.

Virtual labs, such as a virtual wind tunnel or chemistry labs developed at the Ruhr-University Bochum, are a better choice than local labs. These are web-based applications that simulate real engineering test facilities in civil, environmental, and process engineering. Essential parameters such as wind speeds, wind directions or turbulence intensities can be varied in a boundary layer wind tunnel experiment according to realistic configurations or processes. Therefore, the test results, such as the modeled structural response etc., can be experienced virtually (see fig. 1) with the same result as in an on-site lab. The students perform experiments independently from their home PC and evaluate them according to scientific methods and requirements.



Figure 1. 3D virtual representation of the Boundary Layer Wind Tunnel at the Ruhr-Universität Bochum - remote access points are marked "i" and show explanations about steering and sensing of experiments as well as videos of specific experiments; experimental parameters can be varied within a certain range, corresponding data from previous experimental campaigns can be downloaded for further processing.

The idea of the virtual labs was motivated by the fact that specialized laboratories are highly valued by teachers and students. Students in particular appreciate that these labs offer an intensive learning experience. Virtual labs can thus be understood as a complement to specialized laboratories with virtual, but realistic experiments in order to make the students' learning experiences more comprehensive.

Students are expected to plan and conduct experiments on their own. This usually includes planning the measurement series: e.g. preliminary considerations as to which gas flows and which liquid flows need to be measured in order to fulfill the task of the specialized laboratory. After the experiments, the students apply the knowledge gained in lectures. By studying the experimental script to evaluate the measurement results, they formulate statements about the quality of the results. This is necessary because measurement errors and fluctuations can also be incorporated into the model response monitoring within a virtual experiment in order to reproduce the system realistically. Teachers can tailor the application to students' prior knowledge.

Using a provided script, students prepare to conduct the experiment in the virtual test facility, developing the ability to plan a systematic experiment independently. The experiments are designed so that exploratory learning can be used to observe the phenomena described in the experimental script, such as the systematic variation of the main operating parameters of the experimental plant (pressure, temperature, mass flows, etc.). Students should be able to identify measurement errors and outliers and correct them by adjusting the accuracy and reliability or taking additional measurements to increase the statistical stability of the results, if necessary. While the students prepare independently without teacher supervision, the process of the virtual experiment and the evaluation of the results must be supervised by competent teachers.

Following scientific procedures, appropriate documentation and presentation of both the experimental procedure and the results are presented by the students in a report, e.g. in the form of a protocol, possibly with an oral presentation.

The learning objectives are to prepare, plan, execute and evaluate experiments independently, and assess the results in a knowledge-based manner. Exploratory learning enables students to subjectively discover new aspects. At the same time, they become familiar with scientific working processes and acquire sustainable knowledge and skills that go beyond technical and methodological knowledge – above all, independence in decision-making. This enables them to apply what they have learned to new situations and scenarios. These skills are necessary to be able to solve problems in a competent and systematic way later in their careers, and are far more valuable than inert knowledge passively acquired in lectures.

3.1. Virtual labs and virtual exchange

Virtual labs can be made available to students across different countries and expand the scope of learning by involving institutions with different expertise. Besides the greater advantage in knowledge, two other aspects stand out: on the one hand, more students can gain intercultural experience and on the other hand, more equal opportunities are created, especially for students who are often excluded from physical exchanges due to the aforementioned reasons.

When the labs and the assignments are set up so that students from different countries work together in a study group, they learn to interact and collaborate with people from different backgrounds. This is a valuable experience given the increasing importance of international collaborations today. Different perspectives and new insights can be shared through established interaction. In addition, an intercultural learning environment can help those learners who are not from the majority group (Gay, 2018) and may otherwise be excluded.

4. Conclusion

Integrating virtual labs into engineering education has several advantages, if done right. Students can access virtual labs from home; they do not need to be on campus or even in a particular country. As such, virtual labs are much more inclusive, allowing everyone to participate regardless of disability, social background, or the need to work in order to support themselves financially.

In terms of the skills that graduates should have, it has been shown that the learning outcome is much higher when engineering students have the opportunity to test and apply the knowledge they have acquired in lectures in a laboratory; especially in a lab that focuses on a hands-on approach. Availability, didactic variability and cost efficiency are best when the

lab is virtual. Exploratory learning can have a better impact on the comprehension of learning material. This will lead to more independent, self-directed and self-organized future engineers who have more than just passive, scientific knowledge. Students learn the process of researching and applying their skills to real-world tasks. It promotes the ability to identify problems and generate ideas, enabling the learner to understand what needs to be done to find solutions.

A third advantage of virtual labs is their intercultural nature: not only do they offer students the opportunity to acquire knowledge not taught at their home university, but they also give students the chance to gain experience working with people from different cultural and linguistic backgrounds. They learn to overcome and appreciate culturally determined differences in approaching tasks and finding solutions.

Thus, it can be said that including virtual labs has brought significant benefits and lasting improvements to engineering education, broadening the the expertise taught and providing a lower threshold for participation.

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