UNAVOIDABLE QUINTESSENCE OF HANDS-ON LABORATORIES VERSUS VIRTUAL LABORATORIES: AN EDUCATIONAL DILEMMA

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Abstract
Nowadays, open universities stand up for an innovative methodology for teaching and learning distance courses. E-learning education is developed in flexible time and space, active control of the learner’s learning process and new forms of experimentation with knowledge. The student is autonomous to decide the moment and even the way to acquire the knowledge, under assistance, guidance and tracking supervision. However, in the domain of science, technology and engineering, there are more challenges to overcome, because lab practices have to provide effective skill acquisition and hands-on experience. Traditional hands-on laboratory, where students should develop full observation and awareness activities, have been essential for the education of future engineers and scientists for better understanding the strong relationship between the knowledge and professional real-life. Current Information and Communication Technologies (ICT) provides numerous enhanced tools to implement e-learning methodologies on virtual simulated laboratory and remotely triggerable laboratory.

Through a large review of the literature related to these labs in higher education, there are hands-on advocates, who emphasize the design skill as an advantage, while detractors resolutely bet on an innovative technology using a remote lab arguing a better conceptual understanding. Others manifest that the frontiers among the three labs are unclear, since both laboratories (virtual or real) need computers and automation control and that the effect of presence may be as important as technology. Nevertheless, one cannot draw hustle conclusions to firm commitment to virtual labs as total substitute of hands-on ones. There are educational aspects that occur in the development of practices and small projects in the real laboratory which, despite the continuous enhancement of ICT, have not yet been improved or even equaled by the other two types of laboratories.

This paper focuses on this educational dilemma: A comparative study of several types of laboratories available to students of higher education, particularly for engineering degrees, from the point of view of cognitive efficiency and student motivation. It focuses on the practical laboratory in order to put student under circumstances of real interactions, incidents during the experiment and human relations, which is assumed as perceptiveness hardly acquired in virtual labs.

The result of the study reveals the unavoidable quintessence of the hands-on laboratories at the present time, and determines a proper rate between real and virtual methodologies for practices of engineering and scientific disciplines. Also the result points out to strategies for a more efficient acquaintance of knowledge by essays and experiments in a future scenario configured with an extrapolation of the ICT current trend, in such way that the weight of hands-on could be reduced. The future impact of technology on teaching and learning are going to potentially improve the efficiency of virtual labs. In addition, social networking and augmented reality should achieve and compensate human relation experience among hands-on lab participants.

Keywords: virtual lab, hands-on lab, e-learning, engineering, science.

1 INTRODUCTION
Charles Sanders Peirce [1], a logician philosopher and scientist, believed that thought must produce action, rather than dawdle in the mind and lead to indecisiveness. Consequently, only those things that are experienced or observed by a learner are authentic (the evidence of experience). The top-down model, from theory to professional skill, is an obsolete methodology with an inadequate simplification of a reality. Such procedures are unmanageable to represent the current and mutable scenario where complex reciprocal interactions between conceptualisation and pragmatism occur [2].
Since reality is constantly changing, we learn better by applying our experiences and thoughts to problems that are going arising as the world evolves. Pragmatists propose teaching methods focused on hands-on problem solving, experimenting, and project authoring. Also they encourage students to work in groups and bring the disciplines together to focus on solving problems in an interdisciplinary and cooperative way. Rather than hand out pre-elaborated (pre-cooked) knowledge by programmed doses to new learners, Pragmatists believe that learners should apply their knowledge pattern previously acquired to real situations through experimental inquiry [3].

Within the broad educational spectrum of a university, technical and scientific disciplines of engineering degrees highlight their pragmatic approach. The engineering courses inexcusably require the realization of experiments and practices in laboratories installed for this purpose, which complete, strengthen or corroborate the theoretical approach, so that the student acquires fully the professional competences regulated [3] and develop analytical thinking. Analytical thinking happens when student tries to find a causal explanation of a situation or phenomenon, to assess and make a suitable choice, and to see a big depiction of something [5].

Since cognitive psychology tells us that learning is much more efficient by reflecting on the experiment than by listening to a speaker [6], the laboratory is the arena setting that forces students to become involved in the self-learning, by challenging the ignorance and by inquiring the cause of phenomenon observed. Therefore, the laboratory of tests and practices is an inescapable part in the learning of engineering.

Nowadays, open universities stand up for an innovative methodology for teaching and learning distance courses [7]. E-learning education is developed in flexible time and space, with an active control of the learner's learning process and probing new methods spontaneously arisen from the fervent desire to learn. The student is autonomous to decide the moment and even the way to acquire the knowledge, under assistance, guidance and tracking supervision. However, in the field of science, technology, engineering, and mathematics (STEM), there are more challenges to overcome, because lab practices have to provide an effective skill acquisition by testing and hands-on experience [8].

1.1 The proposal

The San Valero group contributes to the sustainable development of society through comprehensive training. It is recognized as a socially responsible educational group, with an important national and international projection, referring to the quality and innovation in its teaching and research activity, the efficiency of its management model and the high level of satisfaction of its students, workers and other stakeholders [9]. The San Valero Group, located in Zaragoza (Spain), is composed, among others, by the entities: Universidad San Jorge (USJ) and Centro de Estudios Abiertos (SEAS). In this context, a group of researchers from USJ and SEAS are studying the adequate methodology for the laboratory practice in on-line engineering courses.

This paper focuses on the comparative study of several types of laboratories available to students of higher education, particularly for engineering degrees, from the point of view of cognitive efficiency and student motivation. Practical or hands-on laboratory tries to put student under circumstances of real interactions with elements and technology, tackling and solving incidents during the experiment and human relations, which are assumed as perceptiveness hardly acquired in virtual labs. Therefore, at first sight, it sounds that a methodology study for engineering e-learning should be completely focused on virtual lab. Nevertheless, authors, stemmed on several years of experience, posed a kind of hypothesis about the impossibility of exclusively accomplishing scientific or technical practices on virtual lab in case of e-learning courses, as well as neither is adequate the exclusive use of hands-on lab for face to face learning. Virtual practices and hands-on practices should be interlaced because there is a strong joining between these different ways to acquire practical knowledge.

Firstly, this paper defines a cohesive methodology to depict the interrelationship among different ways to acquire experience and the insertion of a progressive efficient pragmatism. Then, some results about hand-on practices are exposed from lab practices carried out along two degree courses. As the final word on the value of this study, conclusions highlight the paper's findings and suggest the implications of the new insights over pedagogical community.

2 METHODOLOGY

The proposed methodology is based on the insertion of progressive pragmatism, which starts at the end of the master class whose concepts listed and basic relationships exposed need to be verified to
move on the level of experimentation and hard training. This are named a cohesive pragmatism methodology with a compulsory quintessence of hands-on laboratories included (Figure 1)

![Cohesive pragmatism methodology](image)

In theoretical level, student establishes the fundamentals of the cognitive scheme, collecting basic concepts and main relations. Convey of information takes place normally during the master class. Progressive acquaintance of student is a percolation of knowledge acquired in the theoretical level, starting at a stage where student is feeling like driving his/her own cognitive growth through self-learning, self-experimentation and self-confidence in one's own abilities. The cohesive pragmatic level are composed by three interleave stages: Virtual lab, Hand-on lab and Company internship.

The situation some decades ago could be depicted by the Figure 2. The classical lab installation in the most education centers for practices of STEM is the basic training field to test and corroborate contents given in master class. The incipient technological innovation with new resources tried to gain dedication at expenses of hands-on. On the other hand, professional practices accomplished by students during the company internships made necessary to reduce the practices in education center labs. Therefore, there was a serious threat to period of hands-on laboratory. We dare to mention several high school centers where, several decades ago, chemistry laboratory disappeared and were substituted by computer laboratories.

![The pragmatic level a few decades ago](image)

2.1 Learning by virtual lab

In virtual lab, student tries with an intensive training, playing on perfecting his skills in a discovery challenge. This can be achieved through computer applications that offer virtualization of the rehearsed phenomenon, process simulation, archetypes prototyping, video game scenarios which provides skill strength, support for memorizing the work scheme, knowledge satisfaction and self-confidence for new challenges. Above all, the virtual experiment emphasizes the core of the subject in coloristic and animated escenarios; helps to learn by heart by innumerable repetition of the activities; takes the student to extreme experiences without risks to understand the restrictions and even facilitate the creativity with new occurrences.

2.2 Learning by hands-on lab

Hands-on lab (or indoor Lab) activities provide many potential benefits for STEM students both as for content and process. The hand-on laboratory directly involves the learner, by actively encouraging them to perform programed practices. There are some aspects of the subject that is not possible to be learnt without undergoing by the own individual, otherwise, these cases should be inexorably essayed. Advantages of this kind of laboratory are the reality sensoring, interaction and social adaptation in teams, the ability to tackle the unexpected problem, reaction against incidents, and opportunity of test-error experimentation method. Hence it follows that knowledge obtained through laboratory hands-on experience has proven to be more profound and more lasting [11].
The hands-on laboratory is connected with the virtual lab as previous stage and necessary input. More aspects necessary to be described in classical practices of hands-on lab can be avoided if these activities have been reviewed and trained in preceding virtual lab activities. Therefore, the schedule of both labs must be jointly planned. The results of hands-on lab should not only aim to complete or consolidate knowledge initiated in previous stages (theoretical class and virtual lab), but they should be a preamble for a next stage developed in company internship where practices are more connected with the professional reality.

2.3 Learning by company internship

According to Rafis Abazov [10], the company internship experience should be aiming at one in which student runs to the temporary workplace with a desire to propose brilliant ideas, solve challenging problems and acquire new skills. It is the fervent illusion of those who want to learn and knows with the conviction that their knowledge will be immediately exploited. This is the most professional stage in the pragmatic methodology. To assure successful internship practices, from the hands-on stage the student can be coached from planning simulated situation. Then, the hands-on labs must be modified to be adapted to those in lo possible to professional environments.

2.4 Flexible stage engagement

Under a holistic view of neuroscience, the brain not only interacts with incoming information, but with the entire sensory context in which the learner is involved; i.e., the environment must address the behavior cognitive and emotional elements that take place in a real scenario. In a cohesive methodology for lab practices the position of adaptive separators in Figure 3 should be adapted to the characteristics of the subject and the circumstances of the teaching mode (face to face, blending learning or e-learning). Probably, in the same course, several subjects schedule for practices should have different time sharing and sequentially connected. Whatever, the coordination and engagement of virtual lab and hands-on lab should be essential to optimize the subject schedule and get a real learning-by-doing methodology. The schedule shared by the three stages in the pragmatic level and the content should be cautiously coordinated.

2.5 Progressive pragmatism

The change between virtual and hands-on environment can accomplish progressively, otherwise a drastic change between two stages. In certain technological subjects the practices are developed along successive stages which number can be higher than three stages defined in Figure 3. In technological engineering courses a new methodological requirement for lab practices development is proposed (Figure 4), which includes a new stage: the remote laboratory. This methodology arises to provide a pragmatic continuous learning through virtual laboratory, remote laboratory, practical laboratory and company internship, in such a way, that the practices can be dimensioned according to these stages:
1 **Virtualization** of bases of experiment, description of component and functions, training through videogames or preamble of test actions.

2 **Simulation** of phenomena or laboratory practices on models created by Augmented Reality interface. The augmented user’s perception by integrating virtual objects into a demonstrator to emulate a real time lab practices.

3 **Remote control** of the physical laboratory where the student acts remotely on control systems with the equipment and machinery installed in the laboratory. Remote laboratory has limited accessibility in practice due to the students queuing in large classes, in addition to a possible slow time required to complete some tests.

4 **Hands-on** experiment with direct personal intervention in the physical laboratory in real installations

5 **Blended lab** when the experiment is carried out by a group of students. A few of them is located at the equipment installation in the education center lab, the rest of student at a distance acts with remote control on machines and facilities.

### 3 RESULTS

As an application of this methodology, group of researcher of USJ and SEAS have undergone some experiences in Pharmacy, Microbiology and Physics subjects.

SEAS, an educational institution with more than 60 years, specialized in the industrial and business area training, has developed its own methodology: Open Training System for e-learning, which combines distance teaching with communication new technologies to eliminate physical and geographical barriers, without losing quality in teaching. A good prototype of progressive pragmatic methodology is applied to an engineering course.

#### 3.1 Chemical laboratory activities: virtual vs. face-to-face

Within the academic offer of the Faculty of Health Sciences of the University of San Jorge, specifically in the Pharmacy degree, the first two courses imply a great deal of practical experience in order to engage students for acquiring the basic competences to feel user-friendly with the laboratory tasks. Acquiring these competences (skills and knowledge) will be fundamental for their professional career, being in many cases one of the definitive requirements to access a job that allow them to enter the labour market (pharmacy office, pharmaceutical industry, laboratory of R & D in new drugs, hospital etc ...).

Specifically in the first year of the degree, the subject "Introduction to the laboratory work (ILW)" is focused on teaching and learning basic laboratory operations: pipetting (pipette and micropipette), filtering, weighing and analytical balance, preparation of solutions, determination of melting point, pH adjustment and measurement, consultation of safety data sheets, waste management, etc. In the same course the student applies the knowledge acquired in ILW during the first weeks of courses to other subjects such as "Inorganic Chemistry", "Organic Chemistry" and "Physical Chemistry I". In this second tandem of subjects the student can progressively increase his laboratory skills with other more sophisticated techniques such as distillation, liquid-liquid extraction, filtration and solids crystallization,
thin layer chromatography and column chromatography, UV-Vis spectroscopy, electrochemical measurements, polarimetry, and cryoscopy.

In the second course, the attendance to subjects of experimental profile is maintained with: "Analytical Techniques", "Physical Chemical II", and "Pharmaceutical Chemistry I and II". In general, the competences acquired during the first course are the basic pillars to face the experimental challenges of this advanced set of subjects belonged to the chemical group.

In the 8 years of existence of the degree, one of the problems that have been detected in our students is that, when they reach higher courses, those technical skills and experimental work, considered acquired in the first two years, are forgotten or modified with bad habits. This factor acts to the detriment of the acquisition of new competences (specific to the new subjects and of more clinical disciplines or of pharmaceutical technology) in the practices of higher courses, since valuable time is lost in remembering basic operations. One proposed solutions is the virtualization of laboratories or the development of laboratory practices in a virtual environment. Both types of experiences (virtual and face-to-face) would not be exclusive but complementary. The objectives of developing virtual practices are:

1. The student could carry out the practices as often as he deems necessary.
2. Through virtual repetition of practices, the student will internalize basic operations better than if he only has the experience of having done them in the physical laboratory.
3. When doing practices in a virtual environment, the student's usual fear of "breaking something" disappears, being able to focus practically on obtaining results based on the experiment.
4. Optimization of the time invested in experiments, allowing students to focus on the laboratory experience to learn and strength new practical goals and not use time and effort of the same in things already known.

In addition, the virtualization of laboratories would not only be useful for the on-campus students. Since it allows students reinforce concepts to remember experimental procedures and review them as many times as necessary even in later courses, it would also be useful for on-line students.

However, it should be noted that, at least in the Pharmacy degree, the practical part cannot be minimized or supplemented solely by virtual simulations. The objective of these non-attendance students, who could be from the same country or from another country, would be that through virtualization they acquire this basic knowledge and then they go to carry out the face-to-face practices, it is not so strange the accomplishment of such operations optimizing the work in group, the acquisition of such knowledge, and the practice itself.

3.2 Microbiology laboratory practices

In laboratory microbiology practices it is essential that the student is able to develop previous skills that allow him to cover the gap between the theoretical perspective and laboratory environment. Before dealing with the management of laboratory equipment, with complexity, risks and costs associated with the use of reagents and consumables, a previous autonomous training is recommended for students. Four on-line practices are developed through a video game to provide foundations of the lab experiment, materials and instruments description and iterative training. A strict protocol should be drilled in successive scenarios, and student is required to perform a virtual decision that will be validated. If the procedure chosen is correct, student passes to the next scenario, otherwise a failure causes alarms and generates proper hints for learning. At the end, the final score assesses the student knowledge level, which will permit the student go into hands-on lab. An example of one of these virtual practices is sterilization routines of basic laboratory materials.

3.2.1 PRACTICE 1: sterilization routines of basic laboratory materials

The student learns the procedure to pack various materials for use in microbiology, as well as the dry heat sterilization procedure of these and applies the heat sterilization procedure, in order to find the advantages of the procedure. In microbiology it is imperative that both the material and the culture media are free from all sorts of microorganisms, to avoid erroneous data obtained due to contamination. There are several methods for sterilizing a material according to its nature, the time available, etc. In general, the sterilization may be by heat, by radiation, by chemical methods or by filtration. The end of any of these methods, when referring to a total sterilization, usually eliminate endospores bacteria which are the most resistant biological structures known. Heat sterilization is the
most used and the most effective in most cases. Basically there are two types. For dry heat sterilization, videogame shows how firing material approaching to the flame (handle, test tube mouths, flask necks, needles, spatulas, sowing handle etc.). For the wet heat sterilization, virtual reality permits operating the autoclave device in order to train the ruled protocol.

3.2.2 **PRACTICE 2: preparation of a culture medium**

In the virtual laboratory, the student will learn the basic protocol for the preparation of a culture medium (a food material that is used in the laboratory for the development of microorganisms). After preparation, the culture is inoculated (i.e., organisms are added) and then incubated under conditions that favor microbial growth. In the screen of the application will appear diverse materials that the student must select for the test (such as nutritive agar, sterile petri dishes, magnet / trapping nuclei, probe, laminar flow equipment, etc.).

In a virtual reality, student trains lab protocols with sequential scenarios and repeated tasks, being involved in essential decisions such as: a) preparation of a nutrient agar medium and the performance of the assay should be carried out; b) weighing the required amount of dust according to the manufacturer's instructions; c) adding the powder in a beaker and add the corresponding distilled water; d) adding the solution to the Pyrex glass bottle of 250 mL, leave the screw cap completely closed; d) autoclaving and selection of autoclave parameters.

3.2.3 **PRACTICE 3: Seeding of microorganisms**

In this virtual demonstration, the student will learn the different procedures for planting microorganisms and will acquire the skills with the necessary materials to carry out the planting (process by which we take a portion of microorganisms or inoculum to a nutrient medium for its growth). The student will be able to download a small videogame to watch and training this procedure. Student can observe different types of sowing in a liquid medium, in a solid medium in a tube, or observing how the sowing device with the inoculum slides gently in zigzag on the surface of the medium, trying not to scratch it.

3.3 **Physics laboratory practices**

The objective of the physics hands-on lab is that the student be able to:

- Measure direct and indirect physical quantities with the use of the corresponding instrumentation and taking into account the safety measures.
- Raise awareness that measurements are affected by uncertainty.
- Check for possible sources of error in measurements.
- Prepare a report with statistical processing and analysis of experimental results.

The web-based Physics laboratory takes some characteristics from UNEDLabs project [12], a Spanish network of web-based laboratories for science and engineering education. The use of virtual platform is essential given that can endure all the learning drilling in the pre- and post-practice phases. In addition, you can conduct self-assessment processes to check for learning. Therefore, the student: trains safety measures, equipment managements, procedure to make measurements, statistical processing of experimental results that can be supplied.

3.4 **Engineering laboratory practices**

SEAS have developed an online methodology, with virtual campus and based on the personalized attention and constant monitoring of the study process. Harnessing advanced technologies for online courses, SEAS’ instructors are undergoing singular lab training as a result of continuous updating of lab practices along decades, which could be a good example of progressive pragmatism.

The subject of Programmable Logic Controller (PLC) aims the student configures, programs and understands special computer devices used for industrial control systems, such as oil refineries, manufacturing lines, travel, aerospace, textile, wind power and so on. The basic units have a CPU (a computer processor) which runs a predefined program that logically manages a series of different inputs to produce the outputs for the desired control.
At the first stage, students accomplish complete virtual remote practices to get training in the most basic functions of PLC programming. From distant points, students establish connection with a server situated in the SEAS lab which hosts a general purpose simulation program for PLC programming. The simulator outputs have been wired to a set of real PLC modules. The simulator equipment was designed so that the student should personally be in front of the system, acting handy on the console arranged with a set of physical pushbuttons, selecting the input signals according to the practice planning and observing the outputs in a monitor (Figure 5 A).

Nevertheless, the teachers of this subject, guided in their spirit of avoiding the presence, have developed electronic plate with adaptors to be plugged to the simulator, in order to substitute manual operations of presently physical student, such as pushing a button or bridging a switch. On this way, far away students could remotely act on the simulator as if they really were in front of console. The outputs of the PLCs, represented on a screen of the simulator are sent to the far away student for their observation, and can be supplemented by visual panoramas of the video cameras installed for this purpose.

The next step, as a transit to the experience in the real laboratory, consists of the connection of the PLCs, to actual industrial systems to be controlled and that are installed in SEAS laboratory (Figure 5 B). In this case, although states and positions of system robots can be followed by the far away student by mean of cameras, it is recommendable a more interesting and professional practice methodology. It consists of organizing of students work teams to carry on the practice. At least one of them should physically be monitoring the industrial system equipment to be controlled, while the rest of team is the far away part, with students acting on the industrial system through the PLC,s programed by themselves. The training experience is almost a professional one and developed in the agreement of a team of students.

4 CONCLUSIONS

There are a lot of lab installations in university buildings to carry out practices on science and engineering. The incipient technology invites to abandon or reduce classical practices to be substitute for virtual lesson or guided essays. On the other hand, companies in a competitive market needs professional better adapted to the requirement imposed by a changing world immerse in a global economy. Also, change is happening in and around higher education. However, it is not consist of merely reducing the indoor lab hours at the expense of strengthening virtual lab period, searching a balanced shared time between cyber-learning and reality experienced. The purposed must be more ambitious from a pedagogical aim, by optimize the necessary time dedicated to hands-on practices in physical labs taking account the training hours that student has employed in video-games simulation or e-learning platforms for practices. In such a way, those activities in virtual labs should be complementary to the hands-on practices.
Hands-on lab provides a strong analytical habit, social communication, and trial experience created by the individual for his own cultural benefit. It involves students to observe everything around them, organize the method to test their propositions, develop the process and handle it until a successful accomplishment. In the end, they should be able to explain the results they have obtained or justify the mistakes in case of failure.

Deep understanding or consolidation of knowledge in hands-on experience make student feels author of his/her own knowledge. The acquisition of habits and routines for the systematic application of basic protocols can be an excellent intermediate phase to assure the success in the laboratory.

Technology has accelerated the pace of change in learning-teaching methodology. University needs adjustment in classical labs for science and engineering to prepare students with the skills and mindsets they will need to tackle the current challenge of professional institutions and companies.

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