A new 3D Model to define Laboratory Services

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Abstract: In the last two decades, remote and virtual laboratories have seen an ever-growing acceptance in universities, and this fact has supported a wider adoption of a lab-based education framework, especially in engineering. The reason lies on new possibilities to develop *learning by doing* educational paths, as laboratories allow to achieve important pedagogical objectives. The related research field has two main communities. The former is working on evolution of educational scenarios. The latter deals with technical development of laboratories, and it actually influences the former community's work. Despite the huge amount of works, specific aspects are often discussed singularly, to the detriment of a holistic vision. The present paper wants to approach this issue towards a technical-development perspective. We propose a classification of laboratories, which firstly aims at a common taxonomy to identify their typologies. In our opinion, such a classification helps the research community by allowing to compare different solutions available and, more important, it provides each laboratory implementation with specific technology resources possible to implement and constraints to be faced. This eventually develops into the networks of laboratories characterisation. Although previous works have been already proposed, the technical solutions they refer to have seen great progresses in recent years, thus we start from these useful work to combine their results and propose a new classification of laboratories, by means of a 3D visualisation designed as black-box model combination.

Keywords: lab-based education; lab network initiatives; digital labs, 3D visual lab classification.

1. Introduction

Experimentation and laboratories play a main role in technical education since they provide students with the opportunity to experience professional techniques and practices, and they further allow to learn to manipulate the physical environment and understanding its constraints (Feisel and Rosa, 2005). In natural Science, Technology, Engineering and Mathematics, this means to put mathematics and physics learnt into practice, allowing to compare theoretical simulative models with real equipment and devices behaviour (Heradio *et al.*, 2016). Hands-on labs, as traditional solution, involve high costs relating to equipment, space, and maintenance staff (Gomes and Bogosyan, 2009). For this reason, remote labs have seen a widespread acceptance among universities in the last two decades (Heradio *et al.*, 2016). Generally, remote labs identify labs where the access to the resources is through the internet by means of experimentation interfaces. The resources can be both (i) real, and (ii) mathematical models simulating real device and properly experiments: a preliminary classification identifies the former as remote labs and the latter as virtual lab devices (Zutin *et al.*, 2010). Although these solutions allow to reduce costs (Heradio *et al.*, 2016), remote-access-lab providers have to face different issues. For instance, security and safety are critical, since suitable standards and guidelines are required to implement both networking requirements and local procedures (Uckelmann *et al.*, 2020). Other researches (Potkonjak *et al.*, 2016) highlights the need for high tech stacks and complex frameworks to design and implement the solution. However, the interest of the research community in remote labs lies on some advantages that they offer. Firstly, laboratories over distance still respond to the 'learn by doing' scenario enabled by lab-based education (Leão *et al.*, 2011) and they have clearly proved their academic usefulness (Corter *et al.*, 2004). Secondly, the academic interest comes from the significant benefits they provide compared to traditional solutions, namely (i) improved student access and related increases in use, and (ii) availability of more diverse range of experimentation (Tawfik *et al.*, 2014). As a result, the interest of the research community has risen in two main research fields (Zappatore, Longo and Bochicchio, 2015): (i) the pedagogic scenario, and (ii) the technical and technological lab design, to which we refers as a 'technology' issue in the following. Although these two fields seem to be unrelated, they are intertwined, since technology evolution turns out in educational frameworks (Rubens, Kaplan and Okamoto, 2012). For instance, internet, as engine of distance learning (Feisel and Rosa, 2005), allowed to overcome both (i) technical and social issues, such as unavailability of equipment or funding resources, and (ii) service continuity when Universities are not physically accessible due to political instability. An example of these issues is the unavailability of infrastructures during the COVID-19 emergency nowadays faced worldwide: schools and universities all over the world are closing to better protect the health of their students from coronavirus pandemic, and online mode of teaching allows educators to continue to fulfil their duty otherwise they might be struggling to continue educating their students (Orduña, 2020). Moreover, new developments such as Internet of Things increase the importance of interdisciplinarity with computer science faculties beyond traditional specific curricula (Uckelmann, 2012). Finally, Motyl *et al.* (2017) have discussed the possible changes of engineering education towards Industry 4.0 framework and new digital industrial technologies. Among these, augmented and virtual reality (AR/VR) have gained attention in industrial system engineering, and they have spread applications in maintenance and, more in general, in production control (Damiani *et al.*, 2018). Hence, they are becoming more and more relevant in engineering education. Lots of work have been proposed in scientific literature to depict technology approaches to build, manage and share remote-access labs: for an in-depth analysis we remind to Heradio *et al.* (2016), who have reviewed comprehensively more than 20 years of research. We only state, here, that the majority of studies describe a specific solution implemented. A different approach is the one by Gomes and Bogosyan (2009) who provide an overview of available technologies for the development of remote labs. An important contribution addressing how to characterise and describe remote and virtual labs, regardless the very specificity of the solution implemented, is the one proposed by Romagnoli *et al.* (2020). These authors provide a structure to collect all possible lab information of technical nature and the resulting database works as a real handbook for designing remote-access labs. Although the usefulness of such studies, what it is missing in the scientific community, to our knowledge, is a simple tool to quickly identify lab typologies, and define resources suitable for designing the lab which the provider wants to digitalise. For instance, we experienced that students and, what is more surprising, researchers are very often confused when identifying experimentation and lab typologies. In the present paper we propose a visual tool to classify remote-access labs on the basis of the suitable resources used.

The reminder of the paper is structured as follows. In section 2 we propose an overview of exiting literature on remote labs: we discuss the evolution of engineering labs and the former vocabulary generally used. Then we focus on recent attempts of classifying the nature of labs and we illustrate their merits and limitations that suggested a new classification. Section 3 proposes the methodology adopted, namely the characterisation of the layers of the model. In section 4 we design the model, and then in section 5 we provide a practical use of the tool as its validation. Finally, we provide discussion and conclusions in section 6.

2. A review on lab-based education in engineering

Engineering has always been a practical discipline. The following overview on engineering history is adapted by Feisel and Rosa (2005). A first example of engineering schools was the U.S. Military Academy in West Point, N.Y., founded in 1802 to produce and train military engineers. The school provided students with ab practicum in hands-on labs housed in physical structures built ex-novo. Until the Second World War the engineering education was mainly lab-based. In the late 40s, the engineering switched from more practical lab-based aspect to more academic, theoretical aspect, since the American Society for Engineering Education claimed that engineering needed "first principles" to seek solutions to the problems entailed. The "space race" of 60s and 70s further stressed the focus more on theoretical disciplines because of the need for facing high development costs. In the early 80s the focus moved again on lab experience, since engineers seemed to be unprepared to face 'real world' requirements, beyond just the formulas. New criteria were created that required adequate lab practice, instrumentations, and refurbishments. In the early 90s the focus switched on the accreditation in engineering programs, while in the early 2000s the even increasing accessibility to computers and the possibility to integrate them paved the way to a major focus on technical solutions to provide and to further develop. Eventually, the growing interest in lab experiences triggered the interest in online/internet lab, in the form of (i) simulation and (ii) remote labs, both eventually supported by theoretical courses platforms (Balamuralithara and Woods, 2009). In the next section 2.1 the meaning of both terms, simulation and remote, is explained.

2.1 Vocabulary inconsistencies

Balamuralithara and Woods (2009) stated that there are two approaches to conduct labs online nowadays using the internet and online technologies: (i) simulation and (ii) remote labs. Simulations are used for explaining and reinforcing concepts. Remote labs allow the students to work on real equipment and instrumentation, located at a distance via Internet/Online. The suitability and selection of the type of lab depends on the educational goal of the lab experiment (Henry, 1995). A lab of the same typology can be supplied in different ways and provide different educational scenarios (Kammerlohr *et al.*, 2020). For instance, a local simulation is different from a virtual laboratory. However, lots of studies have struggled to correctly identify lab typologies. In the following we provide the reader with the general qualitative features of the labs, and the terms used in literature to name them. The aim is twofold. Firstly, it highlights the difference between the lab typologies. Secondly, it proves the lack of a common vocabulary: as a result, labs with common (or identical) specifications are named in different way in literature.

Real labs are the physical solution available in two forms: (i) on-site lab and (ii) mobile labs (Rivera and Petrie, 2016). Students works with realistic data, but they also interact collaboratively with actual equipment and a supervisor to find solutions to the experiment. Schedule of experiments and access to lab is limited to time and place. Students need to be physically present at the lab itself in order to participate to the experiments. It is possible to offer **mobile** version however, which widens the access possibility outside the university area (Rivera and Petrie, 2016). Other names for this lab are **hands-on** and **traditional labs** (Brinson, 2015). **Simulation** and **Virtual labs** are difficult to distinguish. As a whole, **simulations**

are efficient supplements to physical labs (Feisel and Rosa, 2005). They are composed of videos, animations, sounds, text, but they could be provided also as a simple global repository of results (De Jong, Sotiriou and Gillet, 2014). **Virtual labs** basically execute mathematical equations relying on mathematical models of the physical phenomena, and simulators have been used as an adjunct to real labs experiment and simulations as well. The real difference between **virtual labs** and **real labs** is that the former is able to work as a substitute of the latter, and furthermore virtual labs exploit internet-based functionality (Zutin *et al.*, 2010). The difference among the type of resources used for the experiment through the internet introduces a further complexity to the lexicon. Authors (Balamuralithara and Woods, 2009; Rivera and Petrie, 2016) used the term **online labs** to identify the use of internet to access to the experiment, performed either by physical or simulating equipment/devices. The need of distinguishing between **remote labs** and **virtual labs** within the **online lab** cluster, relates to (i) technology progresses and availability of tools to design the lab, (ii) to financial aspects, and (iii) to educational outcomes belonging to each different lab typology and furthermore to real labs (Feisel and Rosa, 2005; Balamuralithara and Woods, 2009). **Virtual labs** have been introduced above, whereas the term **remote lab** identifies a system that adopts computer-based technique to interface the students with the physical world, through a web browser access to the real equipment in lab. However, remote solutions are most complicated since they require standardised architectures, and equipment and devices not easy to buy and install (Rivera and Petrie, 2016). Although the term **remote lab** is generally recognised, it is also used the **hand-off lab**, as counterpart of the **hands-on labs** (Feisel and Rosa, 2005). It is worthwhile to note that although there are some authors that propose also the label **hybrid lab** (Zutin *et al.*, 2010; Rivera and Petrie, 2016), these are particular combination of **traditional** and **non-traditional** labs, namely the physical or web access to the resources either simulated or real. To conclude the overview, the internet era has further pushed the distance labs into new concepts, the **internet-based labs.** These labs require new standards when institutes have to integrate lab experiences in their framework, and they further introduce the concept of **Laboratory-as-a-Service** as the use of cloud for providing **remote labs** as a service (Tawfik *et al.*, 2014).

2.2 State-of-the-art in (visual) lab classification

In the present section we address the main concerns previously discussed relating to the characterisation of digitalised lab. First of all, we mention that the present paper has been developed within the international research project on digitalisation of labs named Open Digital Lab for you (DigiLab4U). Whit regards to the adopted taxonomy, we define remote-access labs as labs accessible at distance through a computer network, whereas we use the term Lab Network Initiative (LNI) as the platform or the federated institutions providing them. Furthermore, the following characterisation of labs descends from a previous work of the project, i.e. a classification of labs with respect to their architecture and the service provided (Romagnoli *et al.*, 2020). In that study, the authors have deeply identified the resources useful to characterise remote-access labs of LNIs, and we thus focus on the models identified. We describe them in the following. According to the original studies, models are visually represented in 2D dimensions. We only rearrange characterisations of the original works.

Access-Resource classification (Bencomo Dormido, 2004)

The first real attempt to define a taxonomy belongs to Bencomo Dormido (2004), who has proposed a 2D classification with respect to the 'access to the resource' and the 'nature of the resource' as in the following:

•<u>Local access-real resource</u>. It represents the traditional real lab where the student is in the real plant to carry out the experiment, possibly using computers.

•<u>Local access-simulated resource</u>. The whole environment is software, and the experimentation interface works on a simulated resource, which together with the interface is part of the computer. This configuration would be defined as a mono-user virtual lab.

•<u>Remote access-real resource</u>. It represents access to a real plant equipment lab through the Internet. The user operates and controls in a remote way a real plant through an experimentation interface. This approach is named remote lab.

•<u>Remote access-simulated resource</u>. The student operates with his/her experimentation interface on a virtual system reached through the Internet. The basic difference is that simulated processes can be performed concurrently, thus several users can operate simultaneously with the same virtual system. The lab is a multi-user virtual lab.

Four cases obtained by the combination of local or remote access to the resource, and its real or simulated nature, are showed in Figure 1a. The figure uses the colour miscellaneous rules to match the solutions, i.e. combination of yellow and blue boxes results in green, as well as blue and red fonts result in purple.

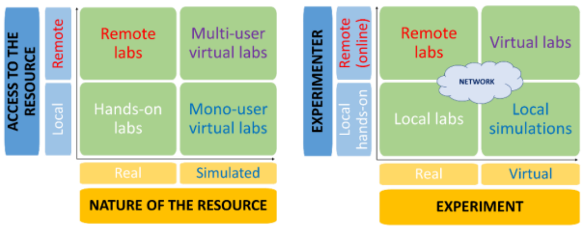
Experiment-Experimenter classification (Zutin *et al.*, 2010)

A further attempt is the one by Zutin *et al.* (2010), who have discussed 'the creation of a common framework to describe laboratories according to the semantic web technology'. They have identified four cases by considering the use of equipment and devices (experimenter) rather than the access to the resources as in Bencomo Dormido (2004). Concerning the remote experiment, they use the term "Online Laboratory" as an environment allowing people to perform both hardware-based experiments and software-based simulations over the Internet. With respect to the layers experiment-experimenter, online labs are:

•<u>Remote Laboratory (properly)</u>. It is an online lab which provides real experiments. It implies the control of real hardware and the realisation of real measurements.

•<u>Virtual Laboratory</u>. A virtual lab is an online lab which provides software simulations.

Figure 1b provide this model and highlights its adoption by Pfeiffer and Uckelmann (2019). These authors address the need of introducing the network of labs, as a possible solution of online labs interlinking partner across locations and increasing the visibility of laboratories and potential consumers. It has been the real trigger to our study since it is still not really addressed in others 2D visual classification.



(a) (b)

Figure 1: 2D representation, rearranging the original works, of (a) Access-Resource classification and (b) Experiment-Experimenter classification. Need for highlighting the networked scenario is stressed

3. Layer characterisation

The representation of each configuration of labs is made by means of Black Box Modelling, which allows to describe OUTPUT and INPUT characterising the lab regardless of their specific internal components. By using Black Boxes, the OUTPUT is the result we are aiming at, i.e. the lab typology. In order to define the INPUT, we take account of the Bencomo Dormido's pillars (2004) to fully describe labs, as both technical frameworks and learning systems. The three pillars are: (i) providing users with learning outcome, (ii) resources use, and (iii) access to the units. We use these pillars to identify three possible resource clusters further combined with characterisation model of labs by Zutin *et al.* (2010), stressing the overlapping of specific resource clusters. These three clusters constitute a three-dimension space, where each INPUT is an axis of the Coordinate System generated. Each axis is here characterised by two units, described in the following using the models of Bencomo Dormido (2004) and Zutin *et al.* (2010). The model by Bencomo Dormido (2004) is focused on resources and equipment, whereas the model by Zutin *et al.* (2010) is focused on the connection of the systems.

•<u>INPUT x-axis</u>: the experiment typology, i.e. the equipment and devices used, the rules to follow and so on. According to Zutin *et al.* (2010), it is the smallest enclosed unit of a lab and allows to observe the behaviour and output of a system. Bencomo Dormido (2004) refers to this item as to the nature of the physical system. The experiment can be real or virtual. Real experiment entails the use of real hardware and the realisation of real measurements, whereas virtual experiment provides software simulation or applications.

•<u>INPUT y-axis</u>: the experimenter location, with respect to the equipment and devices for the experiment execution. It characterises the interactivity nature between experiment and performer (Zutin *et al.*, 2010). The experimenter location can be local or remote. When local, the user manages the equipment being present in the lab, while when remote the user manages the equipment at a distance.

•<u>INPUT z-axis</u>: the access to the resources for experimental purposes (Bencomo Dormido, 2004). It can be on-site or through the web. In the on-site access, the user is connected-to and directly-manages the equipment and devices. On the contrary, when accessing through the web, the user accesses to the lab through the internet.

4. The 3D modelling

The linear combination of two units identified for each axis, produces eight specific lab solutions which is the classification aimed at. The full list of lab configuration is provided in the numbered list below, the order is consistent with the axis progression x-y-z and the increasing complexity of the units. Each unit could be characterised by suitable internal parameters. Although these are not mandatory for our classification, we believe that specifying some examples of internal parameter could help the reader to understand the technical meaning and specificity of each axis.

1. **Real Experiment performed by Local Experimenter On-Site**. Internal parameters of this configuration are equipment, devices and control unit off course, but also consumables, which are very characteristics of real hands-on lab.
2. **Real Experiment performed by Local Experimenter through the Web**. Internal parameters of such a configuration are private ICT infrastructure, protocols and technology, such as intranet, VPN, LAN, but also server-side applications to guarantee security.
3. **Real Experiment performed by Remote Experimenter through the Web**. Internal parameters of this configuration are the user-experience interface, controls for retrofitting the experiment design, internet infrastructure and web platforms, web browser integrated applications, and safety and security stack.
4. **Real Experiment performed by Remote Experimenter On-Site**. Internal parameters in this case are the same of configuration number 2.
5. **Virtual Experiment performed by Local Experimenter through the Web**. The internal parameters of such a configuration are the same infrastructure and technologies of configuration number 2, suitable to access the experiment in different point of the institution; whereas, since the focus on security is less severe, web-based application on the client-side are enough.
6. **Virtual Experiment performed by Local Experimenter On-site**. Internal parameters of this configuration are simulation software and user interface provided as either desktop applications or other intrusive stand-alone applications.
7. **Virtual Experiment performed by Remote Experimenter On-site**. Internal parameters of this configuration are the same of configurations number 2 and 4, and field-bus interconnection as well.
8. **Virtual Experiment performed by Remote Experimenter through the Web**. Internal parameters in this case are the same of configuration

number 3, low-focused on the server side and stressing the concept of service to just the client-side.

This classification sticks to studies of Garcia-Zubia *et al.* (2009), Murray *et al.*, (2010), Özbek, Kara and Ataş (2010), Lindsay, Murray and Stumpers (2011), Henke and Wuttke (2012), and Orduña *et al.* (2013).

It is important to note that further parameters for configurations number 3 and 8 enhance the remote and virtual lab characterisations towards the network scalability. These parameters are (i) Remote Laboratory Management System, (ii) Service-Oriented Architecture, and (iii) the semantic interoperability, i.e. the common information exchange reference model. Configurations are then modelled as black boxes, regardless the internal parameter (see Figure 2). These are the OUTPUTs of possible lab solutions to provide (i.e. the black box). Each one results by the combination of the suitable axis units (i.e. the box INPUTs)

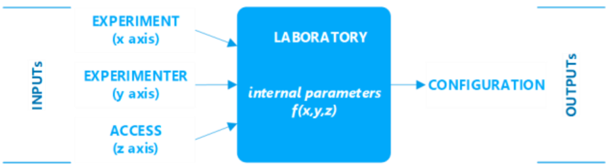


Figure 2: lab as a black box

Black boxes are then inserted in the coordination system according to the proper axis and the units defined. As a result, it is possible to arrange the eight-lab configurations consistently (Figure 3).

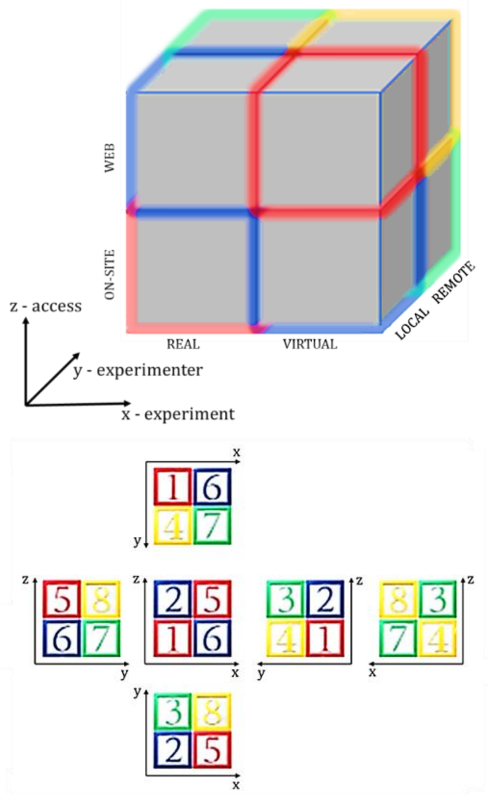


Figure 3: (a) all possible lab configurations in the 3D view, and (b) orthogonal projection of the whole 3D model

Each box develops into a cube within the 3D view in the three dimensions' experiment (x) – experimenter (y) – access (z) (Figure 3a). Furthermore, by using the orthogonal projection is possible to show in a 2D view all the lab-configuration (Figure 3b). We make use of this view to number each black box, otherwise some cubes are difficult to label in the 3D view. Black box '1' (i.e. 'real'-'local'-'on-site') is quintessentially the 'single-spot' configuration, and it represents the majority of historical solutions provided in education, where students access to the lab in the University and manage the experiment by controlling, directly or through the computer, the equipment. Black boxes '2', '5' and '6' represent the "stand-alone configurations", for instance the traditional Informatics labs, the dataset inspection as named by De Jong et al. (2014), and the well-established laboratories with LMS integration. Black box '8' quintessentially represents the web-based configuration, and together with black box '3' they represent the configurations can be implemented in networks of labs. Configurations '4' and '7', although available, are not considered worthwhile to provide, because the remote experimenter accessing directly to the experiment is a solution that seems not useful. We here explicitly mention that each lab configuration is a lab, defined as the sum of experiments to perform (Zutin *et al.*, 2010).

5. Applying the 3D model for classifying digital labs

In this section we provide an application of the 3D model, classifying the laboratory stack of the University of Applied Sciences (HFT) of Stuttgart. The bachelor's degree program of Information Logistics at the HFT of Stuttgart provides the student with lab curriculum to acquire suitable RFID competencies. In the corresponding lab students can use various equipment for testing and researching on RFID technology. The lab consists of various read/write systems for industrial and logistic applications, and a measuring chamber is available for precise signal strength measurements. Up to now the lab has been a real hands-on lab: samples was placed in the measuring chamber by hand under the supervision of a technical employee. Based on the funded research project DigiLab4U, the University is digitalising its lab. In the following we describe the whole lab according to the 3D model to classify labs.

The RFID chamber alone, represents the hands-on part of the lab: it is accessible on-site by experimenter physically operating the experiment where the equipment is sited. Currently, an AR application runs as an operating instruction so that no supervision is required anymore. The experimenter needs to be physically at the University for using university equipment (e.g. holographic calculators). A service robot arm (SRA) automates manual activities on site, and remote software controls the experiment. A VR simulation, running on a platform accessible both on site and by remote, enables realistic mock-up of the chamber. Finally, a combination of the SRA and VR establishes a simulation access using live collected data instead of simulation data (Kammerlohr *et al.*, 2020). Table 1 maps the RFID lab onto the 3D space of the model.

Table 1: RFID lab characterisation, applying 3D model

	Black box	experiment x axis		experimenter y axis		access z axis	
		Real	Virtual	Local	Remote	On-site	Web
RFID chamber	1	X		X		X	
AR laboratory	1,2,6,5	X	X	X		X	X
RFID SRA	1,2,3,4	X		X	X	X	X
VR simulation	5,6,7,8		X	X	X	X	X
VR & SRA	CUBE	X	X	X	X	X	X

6. Conclusions

In the present paper we moved from the engineering education landscape to conclude that, in the internet and distance-technologies era, it is fundamental to clearly define possible technology stacks of labs, and the resources needed. Although studies are developed to classify labs and describe the resources and the technologies adopted when a lab is digitised, the classifications provided belong to different periods, which means different levels of technology development, and they miss a comprehensive overview of the possible solutions to implement. The lack of a uniquely defined and comprehensive model still represents a gap in lab-based education design. Furthermore, research communities of different culture, geography, and history, seem to have very personal vocabulary when they talk about lab-based education. In our opinion the worth of our study, which provides a visual classification of labs by means of a 3D view in a technical-based space, is twofold. Firstly, it suggests the common vocabulary that seems to lack. As the mathematic boosted the research in science because triggered a natural network of scientists all around the research community speaking a common well-defined language to understand everywhere and every time, our study provides the research community of lab-based education with a model to identify the labs typology, towards a common vocabulary of which researchers could benefit for fixing the thematic areas and improving their activities and the whole field. For instance, however the networking is becoming more and more important in lab-based education, it is very missed in previous taxonomy, to such an extent that any classification of labs does not cover this configuration. Furthermore, the simple visualisation framework works as a real tool to support earlier experimenter (e.g. young researcher and students) and could help expert academics when they have to describe possible lab configurations. Secondly, such a classification works as a possible general reference model allowing to better understand the technical requirements with which institutions may deal when they want to digitise their own labs. Since it uses the black box modelling, the classification provided does not depends on the very specificity of labs, i.e. how it is implemented, but just on its configuration. This simplicity is useful to easy identify lab typology. For instance, the network of labs in the 3D view provided is simply highlighted by the position of black box models on top of the 'access' z-axis, regardless the specific technologies adopted to digitalise the lab and make it accessible through the internet. In this sense, the 3D model provided is complementary to other classifications, as the structure provided by Romagnoli *et al.* (2020), and could be considered as its abstraction. In fact, the latter proposes a structure to fully describe the labs, while the one proposed in this study ultimately maps lab typologies with respect to resources in use. Future works could use the 3D model proposed with the aim of providing a comparison amongst remote-access labs digitalised worldwide. The standardisation of resources and the simplicity of the classification is supposed to help researchers in identifying the lab typology even though little information is available. The truth of this statement lies on the experience we did when describing the RFID lab of the Stuttgart University. The application provided for each element of the RFID lab stack, for highlighting the capability of mapping any kind of laboratory, further shows as the present model provides a classification in which specific characteristics can be complementary: for instance, the experimenter of the VR simulation can access to the lab both on-site and on the web. This aspect is missing in other classification, since labs are dually classified, and one configuration seems to exclude the other. Furthermore, the 3D model provided moves from technical basis to provide the lab classification. Research community could apply the framework to other goals, such as defining the pedagogical scenarios counterpart to the technical solutions or classifying the learning outcomes. Both use case of the framework, need to consistently define the axis of the new 3D view. Finally, the simplicity of the representation, make this classification useful to support related science and research field. For instance, within business models for digital labs. The representation provides, in what we believe is a simple and clear way, the characteristic of lab network. It is therefore simple to identify the added value of a specific lab typology. This could help lab managers when defining new ways to create (i) value, (ii) lab use, and (iii) booking processes or expense-based billing.

We are working on some of these topics for future research.

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